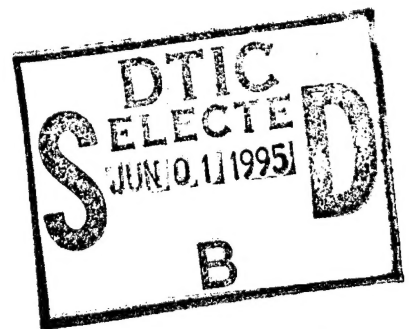


NPS-CS-94-010

NAVAL POSTGRADUATE SCHOOL

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**SOFTWARE REFERENCE:
A VIRTUAL WORLD FOR AN
AUTONOMOUS UNDERWATER VEHICLE**

Donald P. Brutzman

December 1994

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Prepared for:
Naval Postgraduate School
Monterey California 93943

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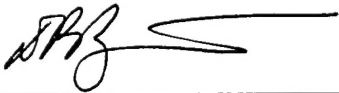
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ABSTRACT

This Software Reference documents and summarizes all source code produced for a Ph.D. dissertation constructing an underwater virtual world for an Autonomous Underwater Vehicle (AUV).

A critical bottleneck exists in Autonomous Underwater Vehicle (AUV) design and development. It is tremendously difficult to observe, communicate with and test underwater robots, because they operate in a remote and hazardous environment where physical dynamics and sensing modalities are counterintuitive.

An underwater virtual world can comprehensively model all salient functional characteristics of the real world in real time. This virtual world is designed from the perspective of the robot, enabling realistic AUV evaluation and testing in the laboratory. Three-dimensional real-time computer graphics are our window into that virtual world.

Visualization of robot interactions within a virtual world permits sophisticated analyses of robot performance that are otherwise unavailable. Sonar visualization permits researchers to accurately "look over the robot's shoulder" or even "see through the robot's eyes" to intuitively understand sensor-environment interactions. Extending the theoretical derivation of a set of six-degree-of-freedom hydrodynamics equations has provided a fully general physics-based model capable of producing highly non-linear yet experimentally-verifiable response in real time.

Distribution of underwater virtual world components enables scalability and real-time response. The IEEE Distributed Interactive Simulation (DIS) protocol is used for compatible live interaction with other virtual worlds. Network connections allow remote access, demonstrated via Multicast Backbone (MBone) audio and video collaboration with researchers at remote locations. Integrating the World-Wide Web allows rapid access to resources distributed across the Internet.

This dissertation presents the frontier of 3D real-time graphics to support underwater robotics, scientific ocean exploration, sonar visualization and worldwide collaboration.

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Many people helped in this work. Mike Zyda is the best dissertation advisor anyone might hope for. His insight, support and enthusiasm are boundless. Bob McGhee and Tony Healey showed unlimited patience and insight as we explored the frontiers of dynamics modeling. Mike Bailey taught me analytical and discrete event simulation. He and Man-Tak Shing also gave valuable advice on the Ph.D. process. Mike Macedonia's unparalleled understanding of computer networks helped make an entire field intelligible.

Dave Pratt blazed the trail with NPSNET, still the best virtual world around and still improving faster than all the others. Dave provided crucial academic advice and also the financial support which made the *SIGGRAPH 94* exhibit at *The Edge* possible. I am indebted to everyone who helped make that weeklong demonstration possible, especially Shirley Isakari Pratt, John Roesli, Frank Tipton, Jim Vaglia, Matt Johnson, Chris Stapleton, Garry Paxinos, Jackie Ford Morie, Theresa-Marie Rhyne, Paul Barham, John Locke, Steve Zeswitz, Rosalie Johnson, Russ and Sue Whalen, Walt Landaker, Dave Marco, Mike Williams, Terry Williams, Hank Hankins and Hollis Berry. I also thank Peter Purdue, Gordon Bradley, Jim Eagle, Ted Lewis, Mike McCann, Bruce Gritton, Mike Lee, David Warren, Dave Norman, John Sanders, Dick Blidberg, SeHung Kwak, Ron Byrnes, Drew Bennett, Jim Bales, Jim Bellingham, Alan Beam, Claude Brancart, Rodney Luck, John Gambrino, and Larry Ziomek for their help. Support for this research was provided in part by the National Science Foundation under Grant BCS-9306252 to the Naval Postgraduate School.

This work is dedicated with love and thanks to my wife Terri and our children Hilary, Rebecca, Sarah and Patrick.

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SOFTWARE REFERENCE

A Virtual World for an Autonomous Underwater Vehicle

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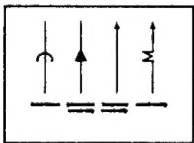


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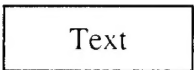


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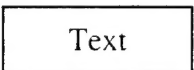


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I. INTRODUCTION

The purpose of this guide is to document the source code developed in the creation of an underwater virtual world for an autonomous underwater vehicle (AUV). It is companion document to a dissertation (Brutzman 94). There are a number of parts to this work. First a users guide is presented which describes how to obtain and install the software described here. Key mission output files then show results produced by the autonomous underwater robot interacting with the virtual world. Remaining chapters present the source code developed for robot execution software, 3D computer graphics, six degree-of-freedom hydrodynamics, a geometric sonar model, networking, and hypermedia using the World-Wide Web and the Multicast Backbone (MBone).

Several languages are included in this source code. Robot execution programs and supporting configuration files are written in the Kernigan and Richie variant of the C language, and run identically under Irix 5.2 or OS-9 operating systems. Other source programs are written primarily in C++. Source code file name conventions use a .c extension for C language files, and a .C extension for C++ language files. Remaining programs and files are written in languages specific to the application, such as *gnuplot* (Williams 95), Tool control language (*Tcl*) (Osterhout 94) (Welch 94), hypertext markup language (.html) (Berners-Lee 94a, 94b) (Hughes 94) or operating system shell scripts.

All of the programs described here are available electronically without charge to Internet users via anonymous ftp. The accompanying public electronic distribution of this reference includes both source code and compiled executable programs. All programs have been tested under SGI operating system Irix 5.2, and robot code has also been tested under operating system OS-9 version 2.3. Goals of the underwater virtual world project include making source code, applications and interfaces easily available in order to encourage scientific collaboration and educational use. Future

work includes porting virtual world viewers to a variety of operating systems and computer architectures.

An NPS AUV hypermedia home page has been prepared to facilitate examination and download of the various underwater virtual world components. This home page is available for interaction using any number of Internet-based browsers, most notably *Mosaic* (NCSA 94a). Resources on the home page include the electronic distribution, installation and execution instructions, pointers to related work, images, plots, papers and a variety of other media. World-Wide Web (WWW) Uniform Resource Locator (URL) for the NPS AUV home page is:

ftp://taurus.cs.nps.navy.mil/pub/auv/auv.html

To learn more about the World-Wide Web, consult "Entering the World-Wide Web (WWW): A Guide to Cyberspace" (Hughes 94). This paper describes everything needed to start using *Mosaic*, accessing all types of information sources, and using hypermedia and the Internet. *Mosaic* is a hypermedia browser that is freely available for Unix machines running X windows, Macintoshes and personal computers (PCs) running Windows. There are also free line mode browsers (such as *lynx* and *www*) that let you browse hypertext documents in a simple text mode using *any* computer which has an internet connection (Montulli 94) (Berners-Lee 94b).

The source code in this software guide is fully documented and reasonably self-explanatory. Graphics and hydrodynamics programs are written in the ANSI standard **C++** language, robot execution code and networking code is written in the Kernighan and Richie variant of the **C** language, plotting programs use *gnuplot* version 3.5 scripting language, and hypertext pages are written in standard Hypertext Markup Language (*.html*) (NCSA 94b). Despite extensive documentation, however, one programmer's clearly-written code may well be undecipherable to another programmer. Users are strongly encouraged to review the companion dissertation which derives the formulae and explains the concepts behind the software (Brutzman 94), retrieve the latest version of the underwater virtual world distribution, or contact the author for questions that remain unanswered. No guarantees of any

kind are implied. Many problems are open and progress occurs on a frequent basis when conducting research on robots and virtual worlds.

Hopefully this work will stimulate and encourage other research efforts to build large-scale virtual worlds in compatibly-extendable ways. Interested readers are encouraged to examine the AUV home page for project updates, read the documentation, and to contact the author regarding new uses of the software and potential research collaboration.

II. INSTALLATION, EXECUTION, CREATION AND REMOVAL

A. Introduction

The following Installation and Execution Guide is intended to enable any new user to download, install, execute and understand the NPS AUV Underwater Virtual World. Users may want to solely download the viewer software to observe an Internet-wide mission exercise, or run the entire set of programs making up the virtual world. Users of the robot execution program can enter their electronic mail address and receive a mission report following each mission. A sample mission report shows the mission script used for the canonical SIGGRAPH 94 mission, a project abstract, pointers to related work and the execution orders generated by the mission script. Mission reports are also available by "fingering" the home auv account, e.g.

finger auv@dude.cs.nps.navy.mil

Finally, shell script files for archive creation and removal are included to document automated archive maintenance.

B. *auv-uvw.INSTALL* Installation and Execution Guide

```
//-----//
Installation & Execution Guide for the NPS AUV Underwater Virtual World
auv-uvw.INSTALL                                19 OCT 94
Don Brutzman                                brutzman@nps.navy.mil
URL: ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.virtual-world.INSTALL
//-----//
```

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- Distribution information
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- Information files
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- Running all of the virtual world components locally
- Plotting mission telemetry using gnuplot
- Recompiling virtual world component executables
- Killing multicast processes
- Removing the entire distribution
- Future work
- Contact information

This is a big project! I've tried to make this guide as concise and readable as possible. However some work is necessary to read and absorb this material.

Suggestions on how to further streamline the guide are very welcome. Thanks!

```
//-----//
Distribution information
```

For the latest greatest distribution, plus pointers to all of the supporting public domain programs, use Mosaic or a World-Wide Web line browser to connect to the NPS AUV home page:

ftp://taurus.cs.nps.navy.mil/pub/auv/auv.html

To retrieve the distribution directly:

ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.tar.Z

To receive a copy of a recent mission report:

finger auv@dude.cs.nps.navy.mil

```
//-----//
System requirements
```

The auv-uvw 'viewer' requires SGI Irix 5.2 or better with OpenInventor 2.0 Execution Only Environment (inventor_eoe) installed. This is provided free with all versions of Irix, it merely needs to be installed. You can tell if it is installed by typing 'versions' at the SGI prompt.

Modification and recompilation of the 'viewer' requires installation of

inventor_dev Inventor 3D Toolkit, 2.0 development option.
The virtual world 'viewer' is written in C++ using OpenInventor
graphics, and it also uses the NPSNET DIS 2.0.3 multicast libraries
(which are also included as source/binaries in this distribution).

The 'dynamics' virtual world software has been tested under Irix 5.2,
is written in C++, and also uses the NPSNET DIS 2.0.3 multicast
libraries. You should run it on a sound-equipped workstation for
best results.

The robot 'execution' code has been tested under Irix 5.2 and OS-9 v2.3
It is written in ANSI C with special #defines for OS-9 K&R C
compatibility, allowing it to be run without modifications either under
Irix or on the NPS Autonomous Underwater Vehicle 68030 microprocessor.
It ought to be portable to most any plain vanilla C compiler.

//-----//

Retrieving the distribution auv-uvw.tar.Z

The easiest way is to retrieve & save the tar file is to point Mosaic at

ftp://taurus.cs.nps.navy.mil/pub/mosaic/auv.html

If instead you use anonymous ftp, here is a sample session:

```
unix>> ftp taurus.cs.nps.navy.mil
Connected to taurus.cs.nps.navy.mil.
220 taurus FTP server (Version 6.10 Wed Mar 18 11:57:03 PST 1992) ready.

Name (taurus.cs.nps.navy.mil:yourname): anonymous
331 Guest login ok, send e-mail address as password.
Password: your.email.address.here

ftp> cd pub/auv
250 CWD command successful.
ftp> binary
200 Type set to I.
ftp> get auv-uvw.tar.Z
local: auv-uvw.tar.Z remote: auv-uvw.tar.Z
150 Opening BINARY mode data connection for auv-uvw.tar.Z(4747669 bytes)
226 Transfer complete.
4747669 bytes received in 34.32 seconds (135.08 Kbytes/s)
ftp> quit
221 Goodbye.
```

The uncompressed distribution is about 10 MB, not counting the extra
recommended applications. The compressed distribution is about 5 MB.
Precise distribution sizes can vary when changes are incorporated.

//-----//

Installing the distribution auv-uvw.tar.Z

Uncompress auv-uvw.tar.Z in your root directory by typing

```
unix:yourhome>    uncompress auv-uvw.tar.Z
unix:yourhome>    tar -xvf  auv-uvw.tar
```

Backup & update your Mbone session directory configuration file .sd.tcl

```
unix:yourhome>    cp .sd.tcl      .sd.tcl.old
```

```
unix:yourhome> cp .sd.tcl.auv-uvw .sd.tcl
```

Edit the MBone tool aliases to include directory paths as appropriate. They are located at the very end of the new file .sd.tcl

```
unix:yourhome> zip .sd.tcl
```

After editing, exit and restart session directory (sd):

```
unix:yourhome> sd
```

You can now run the viewer from an sd advertisement for the NPS AUV Underwater Virtual World (if there is one running - this is optional).

You will notice some auv-uvw information files in your root directory and several new directories:

yourhome/auv-uvw/ OpenInventor viewer program & data files

yourhome/execution/AUV (robot) execution level code and mission scripts

yourhome/dynamics/Virtual world for robot: dynamics, sonar and other components

yourhome/dynamics/speechText-to-speech audio files from mission scripts. These originate from queries to the Say.. server

The auv-uvw distribution should now be fully installed.

//-----//

MBone connection (optional but recommended)

Multicast Backbone (MBone) connectivity is needed if you want to participate in remote exercises. A good way to test your network's connectivity is to type 'sd' (session directory). If you get a menu of MBone programs starting to slowly build up, you are in business.

To receive Distributed Interactive Simulation (DIS) robot execution Protocol Data Units (PDUs) originating on your own network, you do not have to be connected to the Internet-wide MBone.

SGI's Irix 5.2 operating system supports multicast in the kernel, so you can still run the robot/virtual world programs on one machine & the auv-uvw viewer on another. Only one process per machine can grab the multicast port, thus at least 2 machines are needed to run everything.

To connect your system to the MBone takes some work but is worth it. You will need the involvement & support of your network administrator.

The following article tells why MBone is so great and how to connect:

```
ftp://taurus.cs.nps.navy.mil/pub/mbmg/mbone.ps      (PostScript) or
ftp://taurus.cs.nps.navy.mil/pub/mbmg/mbone.html    (hypertext) or
ftp://taurus.cs.nps.navy.mil/pub/mbmg/mbone.txt     (ASCII text)
```

Other installation pointers are on the NPS MBone home page at

ftp://taurus.cs.nps.navy.mil/pub/mosaic/mbone.html

Over a thousand subnets worldwide are already connected to the MBone. There are lots of people willing to help. In practice we've seen it take people between a few days and a few weeks to start using MBone, but once connected further work is rarely required. Good luck!

//-----//

Information files:

auv-uvw.virtual-world.README (a mission report)
auv-uvw.virtual-world.INSTALL (this file)

others are listed in the mission report and the home page site

//-----//

Viewing remotely-executing robot missions via the MBone

You must have MBone connectivity installed on your network for remote experiment observation. If the NPS AUV Underwater Virtual World is advertised in sd, and you have installed the distribution, just select the session and multicast ports are passed automatically to the viewer.

Alternatively, you can start the viewer manually from the command line:

```
unix:yourhome> auv-uvw.viewer  
or    unix:yourhome/auv-uvw.viewer
```

The following command line switches are available with viewer:

```
-address 224.2.2.2 multicast address as advertised in sd session  
-port    #####  multicast wb port as advertised in sd session
```

The virtual world viewer should now run.

//-----//

Running all of the virtual world components locally

Running a robot mission takes three processes and at least two machines. viewer and dynamics must be on different hosts, execution can run anywhere.

Notes regarding sd session advertisements are optional.

- * First is the 'viewer' to get a window into the virtual world. Run this on your most capable Iris workstation - Reality Engines are nice! You can use or disable texturing based on the capabilities of the machine.

```
unix1> cd auv-uvw  
unix1> viewer
```

The following optional command line switches are available with viewer:

```
-address 224.2.2.2 multicast address as advertised in sd session  
-port    #####  multicast wb port as advertised in sd session  
-texture-on  
-texture-off  
-printdialog  pop up print dialog box for screen snapshots  
-noprintdialog
```

The virtual world viewer now runs.

- * The 'dynamics' program is the virtual world connection for robot execution: Run it on a sound-equipped workstation for best results, otherwise ignore any sound-card-missing error messages. The 'dynamics' program is purely text-based so graphics capabilities are irrelevant.

```
unix2> cd dynamics
unix2> dynamics
```

```
Dynamics classes test selections
L loop_test_with_execution_level ();
M Multicast parameter input
ttl=15, group address=224.2.121.93, port=3111
O Ocean current vector reset <0, 0, 0>
H Hmatrix/quaternion exerciser
R Rotation of quaternion & Hmatrix using p q r
D Defaults
I Invert matrix test
E dEad reckon_test_with_execution_level
P PDU_skip_interval change (from 1)
T Toggle TRACE = 0
C DIS_net_close ();
Q Quit
```

Enter choice:

Select L for loop test with execution level

The following command line switches are available with dynamics program:

```
-ttl      #      time to live (be careful!) recommend 16 or less
-address 224.2.###.##multicast address as advertised in sd session
-port     #####  multicast wb port as advertised in sd session
-loop                    start looping automatically
```

- * Finally, 'execution' is the robot execution level software. 'execution' runs through the file 'mission.script' and gets real world responses from the virtual world program 'dynamics'. 'execution' can run under Unix or real-time operating system OS-9.

```
unix3> cd execution
unix3> cp mission.script.the_one_you_want mission.script
unix3> execution remotehost unix1.host.name
```

Enter your e-mail in the execution process window when asked.

See the file mission.script.HELP for info on how to write mission scripts.

//-----//

Plotting mission telemetry using gnuplot

```
unix3:yourhome> cd execution
unix3:yourhome/execution/>gnuplot auv_plot.gnu
```

For fewer points plotted (1 per second) out of the same dataset:

```
unix3:yourhome/execution/>gnuplot auv_plot_1_second.gnu
```

or use a postscript viewer (xpsview or ghostview) to look at plots directly:

```
unix3> xpsview -wp -skipc -or landscape ~/execution/AUV_telemetry.ps &
or unix3> ghostview -landscape ~/execution/AUV_telemetry.ps &
```

//-----//

Recompiling virtual world component executables

auv-uvw directory

(Requires inventor_dev Inventor 2.0 development option installed.
See system requirements section for details).

```
unix3:yourhome/auv-uvw/> make viewer
```

dynamics directory

```
unix3:yourhome/dynamics/> make dynamics
```

execution directory

```
unix3:yourhome/execution/> copy Makefile.SGI Makefile
unix3:yourhome/execution/> make execution
```

```
or OS-9: yourhome/execution/> copy Makefile.OS9 Makefile
OS-9: yourhome/execution/> make execution
```

Details on recompilation and modification are included in all source files.

//-----//

Killing multicast processes

Sometimes multicast processes (such as 'viewer' and 'dynamics') do not die cleanly because they have forked a second multicast process. viewer is especially prone to this behavior when invoked from session directory (sd), since sd must put the viewer process into the background.

You may need to take special action to ensure the processes are killed. The following instructions will work on SGI machines:

To put a process to sleep that refuses to let go of the command prompt:

type a ^Z (control-Z) in the runaway process window

To see what processes are running:

```
unix> ps
```

To see ALL processes that are running (including previous zombie processes):

```
unix> ps -ea
```

To kill a process:

```
unix> kill -9 #### where #### is the Process ID (PID)
```

An example log:

[runaway process, you hit the control-Z key to suspend it]

^Z

Suspended

```
unix>> ps
  PID TTY          TIME CMD
 16558 ttyq3        9:37 viewer
 11289 ttyq3         0:01 tcsh
 16581 ttyq3         0:00 viewer
 16902 ttyq3         0:00 ps
```

```
unix>> kill -9 16558 16581
```

```
unix>> ps
  PID TTY          TIME CMD
 11289 ttyq3        0:01 tcsh
 16904 ttyq3        0:00 ps
```

//-----//

Removing the entire distribution:

Be sure to move any files that you want to save to different directories.

You do not have to remove the old distribution prior to updating to a new version. However you might want to, so that superceded files in old distributions are not left over.

To remove everything, run the shell script `auv-uvw.virtual-world.REMOVE`:

```
unix> source   auv-uvw.virtual-world.REMOVE
```

//-----//

Future work (lots!)

Porting the OpenInventor viewer code to other architectures and porting other virtual world components to other architectures depends on availability of OpenInventor and multicast TCP/IP support. Porting is planned for 1995.

Other people are always welcome to use and extend this code. Please keep me informed of your efforts if you find it of value.

Other research collaborations to extend the underwater virtual world to build up a truly large-scale Internet-wide fully distributed virtual world are of particular interest.

Integrate Dr. Larry Ziomek's Recursive Ray Acoustics (RRA) sonar model.

Incorporate pre-processed terrain datasets for Monterey Bay.

Virtual Reality Modeling Language (VRML) - see the working group <http://www.wired.com/vrml/>

Dissertation "A Virtual World for an Autonomous Underwater Vehicle" is being written and will be made publicly available.

//-----//

Contact information:

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Monterey California 93943-5000 USA	fax (408) 656-2595

//-----//

C. *mission.output.email* Mission Output Electronic Mail Report

The following report is sent by electronic mail to users who execute a robot mission. It demonstrates that robots, once networked, can report back results only when they are of interest or human intervention is specifically desired. The goal is for the robot to meet user directives conveniently, rather than requiring constant monitoring or supervision.

The mission report combines an NPS AUV reference information file, the mission script that drove the robot, and the resulting time line of propulsor and plane surface orders. It is also available by querying the robot account with the Unix "finger" command: *finger auv@cs.dude.nps.navy.mil*

NPS AUV Mission Report

Here is a mission report generated by the Naval Postgraduate School (NPS) Autonomous Underwater Vehicle (AUV) running in an Underwater Virtual World.

This message was created by the operating robot connected to the network. Actual robots with network connections can send reports such as this to research teams and interested individuals when scientific discoveries are made or unusual circumstances occur.

virtually yours, the NPS AUV.

. . . . 8- (nps auv)
. . . . 8- ()

=====

The following Universal Resource Locators (URL's) are pointers that lead to more information about the NPS AUV Underwater Virtual World & related work.

- * The AUV underwater virtual world source code, information files and
- * executable programs (for SGI Irix 5.2 machines) can be used to monitor
- * NPS AUV DIS PDU's from anywhere on the Internet MBone. It is freely
- * available via anonymous ftp as a compressed tar file at
ftp://taurus.cs.nps.navy.mil/pub/auv/auv_uvw.tar.Z
- * NPS AUV home page free software distribution, research summary and
- * anonymous ftp directory:
<ftp://taurus.cs.nps.navy.mil/pub/mosaic/auv.html>
<ftp://taurus.cs.nps.navy.mil/pub/auv/AUVPAPERS>
<ftp://taurus.cs.nps.navy.mil/pub/auv/>
- * Naval Postgraduate School World-Wide-Web (WWW) home page includes many
- * additional pointers to the NPSNET Virtual Battlefield, DIS, MBone, and
- * I3LA regional research around Monterey Bay:
ftp://taurus.cs.nps.navy.mil/pub/mosaic/nps_mosaic.html
- * To learn about Internet audio & video on the Multicast Backbone (MBONE):

ftp://taurus.cs.nps.navy.mil/pub/mosaic/mbone.html

* How the robot voice was synthesized live from text over the Internet using
* Axel Belinfante's "Say..." speech server at University of Twente,
* Netherlands which uses Nick Ing-Simmons' phoneme synthesizer 'rsynth':
http://utis179.cs.utwente.nl:8001/say/?

* Postscript plots (20 pages) of vehicle telemetry during SIGGRAPH mission:
ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/AUV_telemetry.ps.Z

* The people from NPS involved in SIGGRAPH 94 _The Edge_ NPS AUV exhibit:
ftp://taurus.cs.nps.navy.mil/pub/pratts/home.html

* Learning more about the World-Wide-Web, URLs and Mosaic:
* "Entering the World-Wide Web: A Guide to Cyberspace" by Kevin Hughes
http://www.eit.com/web/www.guide/ by Kevin Hughes
ftp://ftp.eit.com/pub/web/guide/guide.61/guide.61.ps.Z hypertext
ftp://ftp.eit.com/pub/web/guide/guide.61/guide.61.txt Postscript
ftp://ftp.eit.com/pub/web/guide/guide.61/guide.61.txt text

* A recent copy of this mission report can be found by an auv account finger:
finger auv@dude.cs.nps.navy.mil

If you can't find taurus.cs.nps.navy.mil, it has IP number 131.120.1.13
Additional references are available on request.

=====

This project is part of a PhD dissertation. Here is the abstract:

A Virtual World for an Autonomous Underwater Vehicle

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brutzman@nps.navy.mil

A critical bottleneck exists in Autonomous Underwater Vehicle (AUV) design and development. It is tremendously difficult to observe, communicate with and test underwater robots, because they operate in a remote and hazardous environment where physical dynamics and sensing modalities are counterintuitive.

An underwater virtual world can comprehensively model all salient functional characteristics of the real world in real time. This virtual world is designed from the perspective of the robot, enabling realistic AUV evaluation and testing in the laboratory. 3D real-time graphics are our window into that virtual world. Visualization of robot interactions within a virtual world permits sophisticated analyses of robot performance that are otherwise unavailable. Sonar visualization permits researchers to accurately "look over the robot's shoulder" or even "see through the robot's eyes" to intuitively understand sensor-environment interactions.

Distribution of underwater virtual world components enables scalability and real-time response. The IEEE Distributed Interactive Simulation (DIS) protocol is used for compatible live interaction with other virtual worlds. Network access allows individuals remote access. This is demonstrated via MBONE collaboration with others outside The Edge, and Mosaic access to pertinent archived images, papers, datasets, software, sound clips, text and any other computer-storable media.

This project presents the frontier of 3D real-time graphics for underwater robotics, ocean exploration, sonar visualization and worldwide scientific collaboration.

=====

Questions, comments and collaborations are welcome. Please contact:

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 Monterey California 93943-5000 USA fax (408) 656-2595

SIGGRAPH 94 Collaborators: Michael J. Zyda, Paul T. Barham, John S. Falby,
 Anthony J. Healey, Shirley Isakari, Rodney Luck,
 Michael R. Macedonia, Robert B. McGhee,
 David R. Pratt, Lawrence J. Ziomek
 Naval Postgraduate School, Monterey California

=====

Your AUV robot mission completed successfully. Here is the mission you ran:

your mission is

mission.script.rotate_test

time 0

timestep 0.1

initialize vehicle

depth 45

position 0 0 45

orientation 0 0 0

thrusters-on

rotate 16

pause

wait 60

rotate 0

thrusters-off

wait 120

step

keyboard

keyboard-off

mission complete

kill

NPS AUV file mission.output.orders: commanded propulsion orders versus time

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

#

timestep: 0.10 seconds

#	time	heading	North	East	Depth	rpm	rpm	stern	stern	vertical	lateral		
#			x	y	z	port	stbd	plane	rudder	thrusters	thrusters		
#										bow/stern	bow/stern		
#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#	timestep:	0.10	seconds										
#	0.0	0.0	0.0	0.0	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#	60.0	0.0	0.0	0.0	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
#	180.1	0.0	0.0	0.0	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

D. *make_auv_uvw_tar* Archive Creation Script

```
# make_auv_uvw_tar:  NPS AUV Underwater Virtual World archive creation script
# Don Brutzman      20 OCT 94

echo create auv underwater virtual world distribution tar file auv-uvw.tar.Z

# Notes:
# do not make this tar on gravyl, it doesn't have enough memory for 'speech'
# ensure mission.script.siggraph was the latest (best) mission run
# this script is not included in the distribution.

# NPS Autonomous Underwater Vehicle (AUV) World-Wide Web Home Page
# ftp://taurus.cs.nps.navy.mil/pub/mosaic/auv.html

cd /n/dude/work/brutzman

echo 'removing old files...'
rm -f auv-uvw.tar
rm -f auv-uvw.tar.Z

# Standard e-mail report becomes the README file
rm -f auv-uvw.virtual-world.README
cp execution/mission.output.email auv-uvw.virtual-world.README
chmod -w auv-uvw.virtual-world.README
tar -cvf auv-uvw.tar auv-uvw.virtual-world.README
rcp auv-uvw.virtual-world.README taurus:~ftp/pub/auv
chmod +w auv-uvw.virtual-world.README
rm -f auv-uvw.virtual-world.README

rm -f auv-uvw.virtual-world.INSTALL
cp execution/auv-uvw.INSTALL auv-uvw.virtual-world.INSTALL
chmod -w auv-uvw.virtual-world.INSTALL
rcp auv-uvw.virtual-world.INSTALL taurus:~ftp/pub/auv
tar -rvf auv-uvw.tar auv-uvw.virtual-world.INSTALL
chmod +w auv-uvw.virtual-world.INSTALL
rm -f auv-uvw.virtual-world.INSTALL

rm -f auv-uvw.virtual-world.REMOVE
cp execution/auv-uvw.REMOVE auv-uvw.virtual-world.REMOVE
chmod +x auv-uvw.virtual-world.REMOVE
tar -rvf auv-uvw.tar auv-uvw.virtual-world.REMOVE
rm auv-uvw.virtual-world.REMOVE

rcp execution/mission.script.HELPTaurus:~ftp/pub/auv

tar -rvf auv-uvw.tar auv-uvw.viewer

tar -rvf auv-uvw.tar auv-uvw/viewer
tar -rvf auv-uvw.tar auv-uvw/viewer.C
tar -rvf auv-uvw.tar auv-uvw/Makefile
tar -rvf auv-uvw.tar auv-uvw/overhang.rgb
tar -rvf auv-uvw.tar auv-uvw/auv.iv
tar -rvf auv-uvw.tar auv-uvw/Jason.iv
tar -rvf auv-uvw.tar auv-uvw/Platform.iv
tar -rvf auv-uvw.tar auv-uvw/Testtank.iv
tar -rvf auv-uvw.tar auv-uvw/testtank.C

tar -rvf auv-uvw.tar auv.html
tar -rvf auv-uvw.tar mbone.html
tar -rvf auv-uvw.tar nps_mosaic.html

tar -rvf auv-uvw.tar .sd.tcl.auv-uvw
tar -rvf auv-uvw.tar .mailcap.auv-uvw
```

```

tar -rvf auv-uvw.tar .cshrc-excerpt.auv-uvw

tar -rvf auv-uvw.tar execution/execution
tar -rvf auv-uvw.tar execution/execution.c
tar -rvf auv-uvw.tar execution/parse_functions.c
tar -rvf auv-uvw.tar execution/globals.c
tar -rvf auv-uvw.tar execution/globals.h
tar -rvf auv-uvw.tar execution/defines.h
tar -rvf auv-uvw.tar execution/errno.h
tar -rvf auv-uvw.tar execution/modes.h
tar -rvf auv-uvw.tar execution/setsys.h
tar -rvf auv-uvw.tar execution/sgstat.h
tar -rvf auv-uvw.tar execution/Makefile*

chmod -w          execution/mission.script.HELP
tar -rvf auv-uvw.tar execution/mission.*
chmod 644         execution/mission.script.HELP

tar -rvf auv-uvw.tar execution/auv_plot.gnu
tar -rvf auv-uvw.tar execution/auv_plot_1_second.gnu
tar -rvf auv-uvw.tar execution/print_plots
tar -rvf auv-uvw.tar execution/disbridge.c
tar -rvf auv-uvw.tar execution/os9sender.c
tar -rvf auv-uvw.tar execution/os9server.c

tar -rvf auv-uvw.tar dynamics/dynamics
tar -rvf auv-uvw.tar dynamics/Makefile
tar -rvf auv-uvw.tar dynamics/*.H
tar -rvf auv-uvw.tar dynamics/*.C

echo 'remove speech/numbers.au originating from high replication counts...'
rm -f          dynamics/speech/2?.au
rm -f          dynamics/speech/3?.au
rm -f          dynamics/speech/4?.au
rm -f          dynamics/speech/5?.au
rm -f          dynamics/speech/6?.au
rm -f          dynamics/speech/7?.au
rm -f          dynamics/speech/8?.au
rm -f          dynamics/speech/9?.au
rm -f          dynamics/speech/1??.au
rm -f          dynamics/speech/2??.au
rm -f          dynamics/speech/3??.au
rm -f          dynamics/speech/4??.au
echo 'the speech directory can get very large and occasionally needs pruning...'
tar -rvf auv-uvw.tar dynamics/speech/*.au

tar -rvf auv-uvw.tar DIS.mcast/*

# The following files are provided separately to reduce tar file size.
#       See the auv home page for remote access instructions
#       ftp://taurus.cs.nps.navy.mil/pub/mosaic/auv.html
# tar -rvf auv-uvw.tar execution/AUV_telemetry.ps
# tar -rvf auv-uvw.tar aaai92ws.ps.Z
# tar -rvf auv-uvw.tar dynamics/www
# tar -rvf auv-uvw.tar execution/gnuplot

ls -l          auv-uvw.tar
echo 'compressing tar file...'
compress auv-uvw.tar

ls -l          auv-uvw.tar.Z
echo 'rcp auv-uvw.tar.Z taurus:~ftp/pub/auv'
rcp auv-uvw.tar.Z taurus:~ftp/pub/auv

echo "archive information on taurus anonymous ftp server:"
rsh taurus 'ls -l ~ftp/pub/auv/auv-uvw.tar.Z'
echo 'make_auv_uvw_tar complete.'

```

E. *auv-uvw.virtual-world.REMOVE* Archive Removal Script

```
# auv-uvw.virtual-world.REMOVE  archive removal shell script

# To run this script, please type the following at the unix prompt:
#   chmod +x auv-uvw.virtual-world.REMOVE
#   source  auv-uvw.virtual-world.REMOVE

# Don Brutzman  19 OCT 94

# NPS Autonomous Underwater Vehicle (AUV) World-Wide Web Home Page
# ftp://taurus.cs.nps.navy.mil/pub/mosaic/auv.html

echo 'remove auv underwater virtual world distribution...'
echo 'be sure you run this from the directory you installed it'
echo '(ordinarily your home directory)'

rm -f      auv-uvw.tar
rm -f      auv-uvw.tar.Z

echo 'warning:  unaliasing rm...'
unalias rm

rm -f -r execution/*
rm -f -r dynamics/*
rm -f -r auv-uvw/*
rm -f -r DIS.mcast/*

# remove any inadvertantly created .dot files
rm -f -r execution/*.dot
rm -f -r dynamics/*.dot
rm -f -r auv-uvw/*.dot
rm -f -r DIS.mcast/*.dot

rmdir      execution
rmdir      dynamics
rmdir      auv-uvw
rmdir      DIS.mcast

rm -f      auv-uvw.viewer
rm -f      auv.html
rm -f      mbone.html
rm -f      nps_mosaic.html
rm -f      .sd.tcl.auv-uvw
rm -f      .mailcap.auv-uvw
rm -f      .cshrc-excerpt.auv-uvw

rm -f      auv-uvw.virtual-world.README
rm -f      auv-uvw.virtual-world.INSTALL
rm -f      auv-uvw.virtual-world.REMOVE
rm -f      auv-uvw.*

echo 'restoring .sd.tcl with your saved .sd.tcl.old, please confirm...'
echo cp .sd.tcl.old .sd.tcl
echo   cp .sd.tcl.old .sd.tcl

echo 'auv-uvw.virtual-world.REMOVE complete.'
```

III. NPS AUTONOMOUS UNDERWATER VEHICLE EXECUTION LEVEL

A. Introduction

The execution level of robot software is the hard real-time process which controls propellers, thrusters, plane surfaces, sonars and other sensors. Hardware interfaces to the robot microprocessor are controlled by the execution level. The execution level is further tasked with interprocess communications with the tactical and strategic levels of the robot architecture (Byrnes 93), as well as the virtual world when operating in the laboratory.

The execution code presented here has been tested under a wide variety of laboratory conditions. Regrettably much of the interface code to actual vehicle hardware has not been tested since early 1994 when a battery explosion caused major damage to the NPS AUV II. Hardware repairs from February through October 1994 were required before in-water testing resumed. Nevertheless pre-explosion hardware interface source code has been retained in place and clearly identified through comments and compile flags. Future work includes verifying hardware interface code (Marco 95), updating the execution code and then running the combined virtual world/real world version of the execution level in the water.

An important benefit of a robot connected to an integrated simulator (Brutzman 92a, 92b, 92c) or underwater virtual world (Brutzman 94) is that robot software development can continue independently of actual robot readiness. Approximately half of the execution level source code presented here was developed during the eight month period that the NPS AUV II was out of commission. This advantage alone proved to be strong justification for the value of providing a network connection to the actual robot microprocessor and software. The essential requirement for integrated simulation in an underwater robotics research and development program has been subsequently confirmed by other researchers (Trimble 94) (Kuroda 94).

Another important strength of the robot software is that the Kernigan and Richie variant C language source code is able to compile correctly under two dissimilar operating systems: SGI Irix 5.2, a Unix variant, and OS-9 version 2.3, a real-time operating system that includes features similar to both Unix and DOS. Compiler directives, customized makefiles and command line aliases are used to provide this cross-platform portability. Network communication via sockets has also been made compatible between these two operating systems. This flexibility has been invaluable for rapid and effective software development. One example out of many is that diagnosis and debugging tools under Unix are far more robust than under OS-9, permitting detection and correction of subtle difficulties not detectable by the OS-9 C language compiler and linker.

Future work includes upgrading execution and tactical level communication links. Currently communications between levels use serial and parallel ports, a highly customized and error-prone hardware arrangement. By adding Ethernet connectivity to the tactical level computer, all software levels will be able to communicate via sockets regardless of what networked processor or workstation they might physically reside on. Additional long term goals include extending Internet protocol compatibility to acoustic telemetry communications. Ultimately underwater robots will be independent nodes on the Internet regardless of whether they are in the laboratory, operating with a tether or swimming freely and autonomously within an acoustic local area network (ALAN). The sophistication of virtual worlds will grow closer to that of the real world as robots and researchers operate in each.

B. *mission.script.HELP* Robot Execution Level Mission Script Syntax

```
//-----//
-/execution/mission.script.HELP          11 October 94
Mission script syntax for NPS AUV execution level control in
the NPS AUV Underwater Virtual World
Don Brutzman                             brutzman@nps.navy.mil
//-----//
```

This file describes how to change and create NPS AUV mission script files. Files and the 'execution' program are in the ~/execution subdirectory.

To run a new mission, copy an existing mission file over file 'mission.script' or edit the mission.script file for a new mission.

Example: unix> cd execution
 unix> cp mission.script.siggraph mission.script
 unix> execution remotehost fletch.cs.nps.navy.mil

Script commands are read by AUV execution level (execution.c) from the "mission.script" default file at the start of each mission.

Some of the following commands will also work when invoked from the command line upon execution.

Here are script keywords (and synonyms) that are currently recognized:

Keywords Synonyms	Parameters [optional]	Description (units in feet or degrees as appropriate)
HELP ? /? -?		Provide a list of available keywords (as specified in this HELP file).
REMOTEHOST REMOTE	hostname hostname	tells execution level to open socket to virtual world which is already executed and waiting on 'hostname' REMOTEHOST is a command line switch. Example: unix> execution remotehost fletch.cs.nps.navy.mil
// /* #		comments follow on this line which are not executed note comments will still be spoken if AUDIO-ON pound sign also indicates a comment if in first column
WAIT execute)	#	Wait (or run) for # seconds (letting the robot
RUN	#	prior to reading from the script file again
TIME WAITUNTIL PAUSEUNTIL	# # #	Wait (or run) until robot clock time # (letting the robot execute its current orders) prior to reading from the script file again
TIMESTEP TIME-STEP	# #	change default execution level time step interval from default of 0.1 sec to # sec
PAUSE		temporarily stop execution until <enter> is pressed

REALTIME		run execution level code in real-time
REAL-TIME		(busy wait at the end of each timestep if time remains)
NOREALTIME		run execution level code as quickly as possible
NO-REALTIME		
NONREALTIME		
NOWAIT		
NO-WAIT		
NOPAUSE		
NO-PAUSE		
MISSION filename		Replace 'mission.script' with 'filename' and start
SCRIPT filename		the new mission
FILE filename		
KEYBOARD		read script commands from keyboard
KEYBOARD-ON		
KEYBOARD-OFF		read script commands from mission.script file
NO-KEYBOARD		
QUIT		do not execute any more commands in this script, but
STOP		repeat the mission again if LOOP-FOREVER is set
DONE		
EXIT		
REPEAT		
RESTART		
COMPLETE		
<ecf> marker		
KILL		same as QUIT but also shuts down socket to virtual world
SHUTDOWN		'dynamics' process.
RPM	# [##]	Set ordered rpm values to # for both propellers
SPEED	# [##]	[or independently set left & right rpm values
PROPS	# [##]	to # and ## respectively]
PROPELLORS	# [##]	maximum propellor speed is +- 700 rpm => 2 ft/sec
COURSE	#	Set new ordered course (commanded yaw angle)
HEADING	#	
YAW	#	
TURN	#	Change ordered course by # degrees
CHANGE-COURSE	#	(positive # to starboard, negative # to port)
RUDDER	#	Force rudder to remain at # degrees
DEADSTICKRUDDER	[#]	Force rudder to remain at 0 [or #] degrees
DEPTH	#	Set new ordered depth (commanded z)
PLANES	#	Force planes to remain at # degrees
DEADSTICKPLANES	[#]	Force planes to remain at 0 [or #] degrees
THRUSTERS-ON		Enable vertical and lateral thruster control
THRUSTERS		
THRUSTERON		
THRUSTERSON		
NOTHRUSTER		Disable vertical and lateral thruster control
NOTHRUSTERS		
THRUSTERS-OFF		
THRUSTERSOFF		
ROTATE	#	open loop lateral thruster rotation control
		at # degrees/sec

NOROTATE		disable open loop lateral thruster rotation control
ROTATEOFF		
ROTATE-OFF		
LATERAL	#	open loop lateral thruster translation control at # ft/sec (positive is to starboard, maximum is 0.5 ft/sec)
NOLATERAL		disable open loop lateral thruster translation control
LATERALOFF		
LATERAL-OFF		
POSITION	# ## ###	reset vehicle dead reckon position to
LOCATION	# ## ###	(x, y, z) = (#, ##, ###)
ORIENTATION	# ## ###	reset vehicle orientation to
ROTATION	# ## ###	(phi, theta, psi) = (#, ##, ###)
CONTINUE		continue reading script & executing, no action performed
GO		
STEP		loop for another timestep prior to reading script again.
SINGLE-STEP		Particularly useful in keyboard mode.
TRACE		enable verbose print statements in execution level
TRACE-ON		
TRACEOFF		disable verbose print statements in execution level
TRACE-OFF		
NOTRACE		
NO-TRACE		
LOOPFOREVER		repeat current mission when done.
LOOP-FOREVER		each repetition is called a 'replication.'
LOOPONCE		do not LOOPFOREVER, stop when end of script is reached
LOOP-ONCE		
LOOPFILEBACKUP		back up output files during each loop replication
LOOP-FILE-BACKUP		to permit inspection while new files are written
		the backup files are in execution directory:
		output.telemetry.previous & output.l_second.previous
ENTERCONTROLCONSTANTS		start a keyboard dialog to enter
ENTER-CONTROL-CONSTANTS		revised control algorithm coefficients
SLIDINGMODECOURSE		Sliding mode course control algorithm (not yet working)
SLIDING-MODE-COURSE		
SLIDINGMODEOFF		Disable sliding mode course control algorithm
SLIDING-MODE-OFF		
SONARTRACE		enable verbose print statements in execution sonar code
SONARTRACEOFF		disable verbose print statements in execution sonar code
SONARINSTALLED		sonar interface hardware cards are installed, use them
PARALLELPORTTRACE		enable trace statements for parallel port communications
AUDIBLE		enable text-to-speech audio output
AUDIO		
AUDIO-ON		
SOUND-ON		
SOUNDON		
SOUND		

SILENT		disable text-to-speech audio output
SILENCE		
NOSOUND		
SOUNDOFF		
SOUND-OFF		
AUDIOOFF		
AUDIO-OFF		
QUIET		
EMAIL		ask user for electronic mail address at mission start,
EMAIL-ON		send user an electronic mail report at mission finish
E-MAIL		
E-MAIL-ON		
EMAILON		
EMAILOFF		disable electronic mail address query feature
EMAIL-OFF		
E-MAILOFF		
E-MAIL-OFF		
NO-E-MAIL		
NO-EMAIL		
NO-E-MAIL		
NCEMAIL		
WAYPOINT	#X #Y [#Z]	Point towards waypoint with coordinates (#X, #Y)
WAYPOINT-ON	#X #Y [#Z]	(depth #Z optional). Leave waypoint control by
		ordering course, rudder, sliding-mode, rotate or
		lateral thruster control.
WAYPOINTFOLLOW		Set mode to arrive at each waypoint before reading the
WAYPOINT-FOLLOW		next mission script command, i.e. continue towards each
		waypoint for however long it takes to reach the standoff
		distance before pausing to read the next command.
WAYPOINTFOLLOWOFF		Disables WAYPOINTFOLLOW mode
WAYPOINT-FOLLOW-OFF		
STANDOFF	#	Change standoff distance for WAYPOINT-FOLLOW and HOVER
STAND-OFF	#	control
STANDOFFDISTANCE	#	
STANDOFF-DISTANCE	#	
STAND-OFF-DISTANCE	#	
HOVER	[#X #Y [#Z]]	Hover using thrusters and propellers for longitudinal
		and lateral positioning at specified or previous
		waypoint
HOVER	#X #Y #Z	[#orientation] [#standoff-distance]
		Uses WAYPOINT control until within #standoff-distance
		of HOVER point (#X, #Y, #Z), then switches to
		HOVER control with [optional] final #orientation
		Full speed (700 RPM) port & starboard is used if
		AUV distance to WAYPOINT is > #standoff-distance + 10',
		then slows to 200 RPM until within #standoff-distance,
		then HOVER control.

C. *execution.c* Robot Execution Level Real-Time Control Program

```

*****/
/*
Program:      execution.c  AUV execution level program
Authors:      Don Brutzman, Dave Marco & Walt Landaker
Revised:      28 October 94
System:       AUV Gespac 68020/68030, OS-9 version 2.4
Compiler:     Gespac cc Kernighan & Richie (K&R) C

Compilation:  ftp>      put execution.c
               auvsim1> chd execution
               [68020]  auvsim1> make -k2f execution
               [68030]  auvsim1> make      execution

               [Irix ]   fletch> make execution

Execution:
               [Irix ]   fletch> cd execution
               fletch>   execution remote dynamics-hostname

               where dynamics-hostname is the IP name of the host running
               the dynamics (virtual world) program

Plotting:     see gnuplot scripts 'auv_plot.gnu' and 'auv_plot_1_second.gnu'
               fletch> gnuplot auv_plot.gnu

Debugging:    gravyl:~brutzman/execution>> lint -lm execution.c

               lint -lm -lglobals.h -Idefines.h globals.c parse_functions.c \
               execution.c

               fletch> make warnings

Description:   closed loop for operation during vehicle in-water
               missions as well as in virtual world

Active changes: Don Brutzman   working lab/virtual world networked version
                  & tactical level interface

               Dave Marco      working vehicle code
                  & interfacing physical devices

Future work:   Update digital <==> analog access for new vehicle hardware
               Retest code after vehicle repaired
               Sonar/altimeter integration code reintegrated/retested
               Audio strings seem to be generated differently by OS-9
               standardize parsing of command line and script commands
               finish sliding mode control

               change serial/parallel comms to sockets once
               tactical level gets an Ethernet card

Testing interprocessor connections:
```

```

parallel port  /P          OS-9 auvsim1> mfi_a3

                        LPT1:      DOS  auvsim2> portfix
                                > print filename.txt

serial port    (/T1) /TT   OS-9 auvsim1> wr2t1          then write text
                        OS-9 auvsim1> rdt1a          then read text
                        DOS  auvsim2> C:\COMM\PROCOMM
                                then <alto> for chat mode
                                <altF10> help, <altX> exit

```

Interfaces:

```

Telemetry sent      via serial  port /tt [== /t1 at high baud rate]
Telemetry received  via parallel port /P

```

Telemetry is optionally passed to/from tactical level running on 80386

```

Reads files:        mission.init  [mission initialization data file  ]
Writes files:       output.data   [vehicle telemetry state vector data]
                   output.auv     [tactical order/executive report log]

```

Sonar commands/replies via device port /t3

Note that %F double formats are used instead of %lf on scanf() and sscanf()
calls for OS-9 compatibility

```

*
/*****/
#include "globals.h"
#include "defines.h"

/*****/
/* function prototypes */

/* is there some way to put parameter specifications in the prototypes?? */
/* only if we buy the ANSI C compiler from Microware (or shift to VxWorks) */

void      closed_loop_control_module      ();
void      get_control_constants           ();
double    depth                          ();
double    calculate_psi                   ();
void      zero_gyro_data                 ();
void      initialize_dacs                 ();
void      initialize_adcs                 ();
void      control_surface                 ();
void      rudder                         ();
void      planes                         ();
void      main_motors_off                 ();
void      alive                         ();
void      record_data_on                  ();
void      record_data_off                 ();
void      record_data                     ();
double    roll_angle                     ();
double    pitch_angle                    ();
double    heading                        ();
double    roll_rate_gyro                  ();
double    pitch_rate_gyro                 ();
double    yaw_rate_gyro                   ();
double    stbd_motor_rpm                  ();
double    port_motor_rpm                  ();
double    get_speed                       ();
void      get_init_avg                    ();
void      get_avg_rng                     ();

void      open_device_paths               ();

```

```

void      close_device_paths      ();
void      read_parallel_port      ();
void      dac1                     ();
void      dac2b                    ();
int       adc1                     ();
int       adc2                     ();
void      Init_PortA               ();
void      Init_PortB               ();
unsigned char Read_PortA           ();
unsigned char Read_PortB           ();
unsigned short Read_PortAB         ();
void      set_bsyA                 ();
void      rst_bsyA                 ();
int       ck_sta                   ();

void      center_sonar             ();
char      query_sonar_1_reply      ();
void      set_step_size            ();
void      tty_mode                 ();

void      print_valid_keywords     ();

void      open_virtual_world_socket ();
void      shutdown_virtual_world_socket ();
void      send_data_on_virtual_world_socket ();
void      get_stream_from_virtual_world_socket ();

double    degrees                  ();
double    radians                  ();
double    normalize                 ();
double    normalize2               ();
double    radian_normalize         ();
double    radian_normalize2        ();
void      clamp                    ();

double    atan2                    ();
double    sinh                     ();
double    cosh                     ();
double    tanh                     ();

double    sign                     ();

/* from parse_functions.c */

extern void parse_command_line_flags      ();
extern void parse_mission_script_commands ();
extern void parse_mission_string_commands ();

/*****
/* OS-9 ~ specific function compatibility */
*****/
#ifdef (sgi)

void      tsleep   (unsigned svalue) { /* null body */}

void      _sysdate (format, time, date, day, tick)
            int format, *time, *date, *tick; short *day;
            { /* null body */}

double    pow      (xx, yy) /* power function */
            double xx, yy;
            {return exp (yy * log (xx));}

int       _gs_rdy   (path) int path; { return 0; } /* bytes waiting on path */
int       _gs_opt   (path, buffer)

```

```

        int path; struct sgbuf *buffer;
        { return 0; }

int      _ss_opt (path, buffer)
        int path; struct sgbuf *buffer;
        { return 0; }

#endif

/*****

/*****
/*****

main (argc, argv)

    int argc; char **argv;    /* command line arguments */
{
    if (TRACE && DISPLAYSCREEN) printf ("[start main:  execution]\n");

    strcpy (virtual_world_remote_host_name, VIRTUAL_WORLD_REMOTE_HOST_NAME);

    dt = TIMESTEP;

    parse_command_line_flags (argc, argv);

    get_control_constants ();

    initialize_dacs ();
    initialize_adcs ();

    open_device_paths ();

    record_data_on ();          /* Open files for data logging      */

    open_virtual_world_socket (); /* open connection to virtual world */

    if (strlen (buffer) > 0)
        send_data_on_virtual_world_socket (); /* SILENT? send to sound driver */

    strcpy (buffer, " A U V virtual world socket is open");
    send_data_on_virtual_world_socket (); /* buffer containing message sent */

    *****/
do      /* while (LOCATIONLAB && LOOPFOREVER) */
{      /* indefinite repeat loop for long-duration lab testing */
    /*-----*/

    if (DISPLAYSCREEN)
    {
        if (LOCATIONLAB && (EMAIL == TRUE))
        {
            strcpy (buffer, " Please Enter Your E-mail Address");
            send_data_on_virtual_world_socket (); /* buffer containing msg sent */
            printf ("%s *** HERE ***: ", buffer);
            strcpy (email_address, "");
            gets (email_address);
            sprintf (buffer, "Thanks %s\n", email_address);
            printf ("%s\n", buffer);
            send_data_on_virtual_world_socket (); /* buffer containing msg sent */

            if ((int) (strlen (email_address) > 2) &&
                (strcmp (email_address, "brutzman") != 0) &&
                (strcmp (email_address, "BRUTZMAN") != 0))
            {
                emailaddressfile = fopen (EMAILADDRESSFILENAME, "a"); /* append */
                fprintf (emailaddressfile, "%s\n", email_address);
            }
        }
    }
}

```

```

        fclose (emailaddressfile);
    }
}
else if (LOCATIONLAB == FALSE)
{
    alive (10, start_dwell); /* Wag fin every 10 seconds for total duration
                             of start_dwell seconds */
    printf(" Position AUV for Directional Gyro Offset Measurement\n");
    printf(" Rate Gyro zero measurement\n");
    printf(" Hit <Enter> on AUV When Ready *** Here ! ***\n");
    answer = getchar (); /* pause */
}
printf(" OK!! Starting the mission.\n");
}
parse_mission_script_commands (); /* read initial script orders */
zero_gyro_data (); /* Get daily zeros for gyros */
if (SONARINSTALLED) center_sonar (); /* must have open_device_paths 1st */
strcpy (buffer, " , , , ,"); /* pause */
send_data_on_virtual_world_socket (); /* buffer containing msg sent */
strcpy (buffer, " A U V is starting");
send_data_on_virtual_world_socket (); /* buffer containing msg sent */

/* Initialization of closed loop parameters */

buffer_index = 0;
telemetry_records_saved = 0;
mission_leg_counter = 0;
end_test = FALSE;
wrap_count = 0;
t = 0.0;

/*-----*/
/* Main program operational loop code */
/*-----*/
if (TRACE && DISPLAYSCREEN)
    printf ("[Starting main program operational loop code... ]");

previousloopclock = clock ();

/*-----*/
while (end_test == FALSE) /* this is the realtime main operational loop */
/* when end_test == TRUE then loop is done */
{
    closed_loop_control_module (); /* closed loop code is here <<<<<<<<<*/
}
/* end of real-time main operational loop */
/*-----*/

/* lab version may repeat forever for long-duration testing: */
replication_count ++;

if (LOCATIONLAB && LOOPFOREVER && DISPLAYSCREEN)
{
    printf ("\n[LOOP FOREVER enabled, next loop is replication %d...]\n",
            replication_count);
    sprintf (buffer, " LOOP FOREVER enabled, next loop is replication");
    send_data_on_virtual_world_socket (); /* buffer msg sent */
    sprintf (buffer, " %d", replication_count);
    send_data_on_virtual_world_socket (); /* buffer msg sent */
}

if (LOCATIONLAB && LOOPFOREVER)
{

```

```

/* reset amount of time to wait for next command */
time_next_command = 0.0;
t = 0.0;
if (DISPLAYSCREEN)
{
    printf ("\nLoopforever reset time: [time_next_command = 0.0] ");
    printf (" [t = 0.0]\n");
}
}

if (LOOPFILEBACKUP)
{
    record_data_off ();

#if defined(sgi)
    printf ("rm                                output.telemetry.previous\n");
    system ("rm                                output.telemetry.previous" );
    printf ("cp mission.output.telemetry output.telemetry.previous\n");
    system ("cp mission.output.telemetry output.telemetry.previous" );
    printf ("rm                                output.1_second.previous\n");
    system ("rm                                output.1_second.previous" );
    printf ("cp mission.output.1_second output.1_second.previous\n");
    system ("cp mission.output.1_second output.1_second.previous" );
#else
    printf ("del                                output.telemetry.previous\n");
    system ("del                                output.telemetry.previous" );
    printf ("copy mission.output.telemetry output.telemetry.previous\n");
    system ("copy mission.output.telemetry output.telemetry.previous" );
    printf ("del                                output.1_second.previous\n");
    system ("del                                output.1_second.previous" );
    printf ("copy mission.output.1_second output.1_second.previous\n");
    system ("copy mission.output.1_second output.1_second.previous" );
#endif

    if (LOCATIONLAB)
    {
        strcpy (buffer, " telemetry data backup complete");
        send_data_on_virtual_world_socket (); /* buffer msg sent */
    }
    else /* don't bother backing up most recent results */
    {
        if (LOCATIONLAB && LOOPFOREVER)
        {
            rewind (auvtextfile);
            rewind (auvdatafile);
            if (TRACE && DISPLAYSCREEN)
                printf ("[auvtextfile & auvdatafile rewound to ");
            printf ("output.data.previous & output.auv.previous]\n");
            strcpy (buffer, " telemetry data backup skipped");
            send_data_on_virtual_world_socket (); /* buffer msg sent */
        }
    }

    fflush (auvscriptfile);
    if (fclose (auvscriptfile) == 0)
    {
        if (DISPLAYSCREEN)
            printf ("[success closing auvscriptfile mission.script.backup]\n");
    }
    else if (DISPLAYSCREEN)
        printf ("[failure closing auvscriptfile mission.script.backup]\n");

    fflush (auvordersfile);
    fclose (auvordersfile);
}

/*
#if defined(sgi)

```

```

        if (TRUE && DISPLAYSCREEN)
            printf ("rm                                mission.output.orders\n");
            system ("rm                                mission.output.orders" );
            printf ("mv  mission.output.orders.backup mission.output.orders\n");
            system ("mv  mission.output.orders.backup mission.output.orders" );
        #else
            printf ("del                                mission.output.orders\n");
            system ("del                                mission.output.orders" );
            printf ("copy mission.output.orders.backup mission.output.orders\n");
            system ("copy mission.output.orders.backup mission.output.orders" );
            printf ("del mission.output.orders.backup\n\n");
            system ("del mission.output.orders.backup" );
        #endif
    */

    /* - - - - - orders - - - - - */

    #if defined(sgi)
        sprintf (buffer, "rm %s\n",                                AUVORDERSFILENAME);
    #else
        sprintf (buffer, "del %s\n",                                AUVORDERSFILENAME);
    #endif
    if (DISPLAYSCREEN) printf ("%s\n", buffer);
    system (buffer);

    #if defined(sgi)
        sprintf (buffer, "mv  %s.backup %s\n", AUVORDERSFILENAME, AUVORDERSFILENAME);
    #else
        sprintf (buffer, "copy %s.backup %s\n", AUVORDERSFILENAME, AUVORDERSFILENAME);
    #endif
    if (DISPLAYSCREEN) printf ("%s\n", buffer);
    system (buffer);

    #if defined(sgi)
    #else
        sprintf (buffer, "del %s\n",                                AUVORDERSFILENAME);
        if (DISPLAYSCREEN) printf ("%s\n", buffer);
        system (buffer);
    #endif

    /* - - - - - e-mail - - - - - */

    #if defined(sgi)
        sprintf (buffer, "rm %s\n",                                AUVEMAILFILENAME);
    #else
        sprintf (buffer, "del %s\n",                                AUVEMAILFILENAME);
    #endif
    if (DISPLAYSCREEN) printf ("%s\n", buffer);
    system (buffer);

    #if defined(sgi)
        sprintf (buffer, "cp  %s %s\n", AUVINFOFILENAME, AUVEMAILFILENAME);
    #else
        sprintf (buffer, "copy %s %s\n", AUVINFOFILENAME, AUVEMAILFILENAME);
    #endif
    if (DISPLAYSCREEN) printf ("%s\n", buffer);
    system (buffer);

    #if defined(sgi)
        sprintf (buffer, "cat %s >> %s\n", AUVSCRIPTFILENAME, AUVEMAILFILENAME);
    #else
        sprintf (buffer, "list %s >> %s\n", AUVSCRIPTFILENAME, AUVEMAILFILENAME);
    #endif
    if (DISPLAYSCREEN) printf ("%s\n", buffer);
    system (buffer);

```

```

#if defined(sgi)
    sprintf (buffer, "cat %s >> %s\n", AUVORDERSFILENAME, AUVEMAILFILENAME);
#else
    sprintf (buffer, "list %s >> %s\n", AUVORDERSFILENAME, AUVEMAILFILENAME);
#endif
    if (DISPLAYSCREEN) printf ("%s\n", buffer);
    system (buffer);

    if ((int) (strlen (email_address) >= 3) && (EMAIL == TRUE))
    {
        sprintf (buffer, "mail %s < %s", email_address, AUVEMAILFILENAME);
    }
#if defined(sgi)
    printf ("%s\n", buffer);
    system (buffer);
#else
    /* system (buffer); /* e-mail not available directly on OS-9 */
    send_data_on_virtual_world_socket (); /* buffer msg sent anyway */
#endif
}

/* permit changing the vehicle mission during continuous lab testing */
if (LOCATIONLAB && LOOPFOREVER)
{
    get_control_constants ();
    previousloopclock = clock ();
    record_data_on ();

    strcpy (buffer, " Load mission again");
    send_data_on_virtual_world_socket ();
    /* buffer containing message sent */
}

; while (LOCATIONLAB && LOOPFOREVER); /* end of lab infinite loop (if any) */
/*****

main_motors_off (); /* all done, turn them off */

if (TRACE && DISPLAYSCREEN)
    printf ("[sending 'shutdown' message to virtual world dynamics]\n");

strcpy (buffer, "shutdown"); /* must start with 'shutdown' to die */
send_data_on_virtual_world_socket (); /* buffer containing message sent */

shutdown_virtual_world_socket (); /* close connection to virtual world */

close_device_paths ();

record_data_off ();

if (TRACE && DISPLAYSCREEN)
    printf ("[finishing main: fflush (stdout), fflush (stderr)]\n");

fflush (stdout);
fflush (stderr);

if (TRACE && DISPLAYSCREEN) printf ("[main exit: return (0)]\n");

#if defined (sgi)
    if (DISPLAYSCREEN) printf ("gnuplot auv_plot_1_second.gnu\n");
    system ("gnuplot auv_plot_1_second.gnu"); /* display plotted results */
#endif

    return (0); /* main program exit */

} /* end main program block, execution is complete */

/*****/

```

```

/*****
void closed_loop_control_module ()
{
    if (TRACE && DISPLAYSCREEN)
        printf ("[start closed_loop_control_module]\n");

    /* Speed Control *****/
    speed = get_speed ();

    rpm = (port_rpm_command + stbd_rpm_command) / 2.0;
    clamp (& rpm, 700.0, -700.0, "rpm"); /* bound maximum RPM */
    if (TRACE && DISPLAYSCREEN)
        printf ("[clamp (& rpm, 700.0, -700.0, \"rpm\") complete]\n");

    /* Main_Motor RPM Control *****/
    /* note thruster use does not preclude propeller use */
    if (LOCATIONLAB == TRUE)
    {
        port_rpm = port_rpm_command;
        stbd_rpm = stbd_rpm_command;
    }
    else /* in water, propeller control */
    {
        port_rpm = port_motor_rpm ();
        stbd_rpm = stbd_motor_rpm ();
    }

    if (NOT_YET_REIMPLEMENTED)
    {
        main_motor_delta1 = fabs(rpm) - stbd_rpm;
        main_motor_delta2 = fabs(rpm) - port_rpm;

        /* this is reset windup for proportional integral control of motor speed */
        /* in order to prevent accumulating the integral of speed error */
        if (main_motor_delta1 > 50.0) main_motor_delta1 = 50.0;
        if (main_motor_delta2 > 50.0) main_motor_delta2 = 50.0;

        main_motor_volt1 = main_motor_volt1 + (rpm/fabs(rpm)*0.2*main_motor_delta1);
        main_motor_volt2 = main_motor_volt2 + (rpm/fabs(rpm)*0.2*main_motor_delta2);

        if (main_motor_volt1 > 1023) main_motor_volt1 = 1023;
        if (main_motor_volt1 < 0) main_motor_volt1 = 0;
        if (main_motor_volt2 > 1023) main_motor_volt2 = 1023;
        if (main_motor_volt2 < 0) main_motor_volt2 = 0;

        dac1(main_motor_volt1, RIGHT_MOTOR);
        dac1(main_motor_volt2, LEFT_MOTOR);
    }

    /* if using virtual world dynamics, network is source of values <<<<<<< */
    phi = roll_angle (); /* read roll angle */
    theta = pitch_angle (); /* read pitch angle */
    psi = calculate_psi (); /* Read heading */

    p = roll_rate_gyro (); /* read roll rate */
    q = pitch_rate_gyro (); /* read pitch rate */
    r = yaw_rate_gyro (); /* Read yaw rate */
    z = depth (); /* Read depth */

    /* note: in laboratory using virtual world, values above are superceded */
}

```

```

/* Control laws **** NOTE: all k_ constants must be (+) positive **** */

waypoint_distance = sqrt ( (x - x_command) * (x - x_command)
                          + (y - y_command) * (y - y_command));

/* use WAYPOINTCONTROL (not HOVERCONTROL) until within standoff_distance */
if ((HOVERCONTROL == TRUE) && (waypoint_distance > standoff_distance))
{
    WAYPOINTCONTROL = TRUE;
    DEADSTICKRUDDER = FALSE;
    if (waypoint_distance > standoff_distance + 10.0)
    {
        port_rpm_command = 700;
        stbd_rpm_command = 700;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
%5.1f\n",
t, psi_command, x_command, y_command, z_command,
port_rpm_command, stbd_rpm_command,
rudder_command, planes_command,
bow_lateral_thruster_command,
stern_lateral_thruster_command,
bow_vertical_thruster_command,
stern_vertical_thruster_command);
    }
    else
    {
        port_rpm_command = 200;
        stbd_rpm_command = 200;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
%5.1f\n",
t, psi_command, x_command, y_command, z_command,
port_rpm_command, stbd_rpm_command,
rudder_command, planes_command,
bow_lateral_thruster_command,
stern_lateral_thruster_command,
bow_vertical_thruster_command,
stern_vertical_thruster_command);
    }
}
else if ((HOVERCONTROL == TRUE) && (WAYPOINTCONTROL == TRUE))
/* restore proper HOVERCONTROL */
{
    WAYPOINTCONTROL = FALSE;
    DEADSTICKRUDDER = TRUE;
    rudder_command = 0.0;
    psi_command = psi_command_hover;
    port_rpm_command = 0;
    stbd_rpm_command = 0;
    fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
%5.1f\n",
t, psi_command, x_command, y_command, z_command,
port_rpm_command, stbd_rpm_command,
rudder_command, planes_command,
bow_lateral_thruster_command,
stern_lateral_thruster_command,
bow_vertical_thruster_command,
stern_vertical_thruster_command);
}

if (WAYPOINTCONTROL == TRUE)
{
    /* note that a reversed x,y calling sequence is necessary */
    /* in order to get correct quadrant alignment */
    waypoint_angle=normalize(degrees(atan2 (y_command - y, x_command - x)));
}

```

```

psi_command    = waypoint_angle;
if (TRACE)
{
    printf ("WAYPOINTCONTROL psi_command = %5.1f, ", psi_command);
    printf ("x = %5.1f, y = %5.1f\n", x, y);
}
if ((FOLLOWWAYPOINTMODE == TRUE) && (HOVERCONTROL == FALSE) &&
    ((waypoint_distance > standoff_distance) ||
     (fabs (z - z_command) > standoff_distance)))
{
    if (TRACE) printf ("[FOLLOWWAYPOINTMODE check]");
    /* continue until WAYPOINT reached without further script orders */
    time_next_command = t + 2.0 * dt;
}
else /* WAYPOINT reached */
{
    if (TRACE) printf ("[FOLLOWWAYPOINTMODE success, WAYPOINT reached]");
    fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
%5.1f\n",
        t, psi_command, x_command, y_command, z_command,
        port_rpm_command, stbd_rpm_command,
        rudder_command, planes_command,
        bow_lateral_thruster_command,
        stern_lateral_thruster_command,
        bow_vertical_thruster_command,
        stern_vertical_thruster_command);
}
else if (HOVERCONTROL == TRUE)
{
    waypoint_angle=normalize(degrees(atan2(y_command - y, x_command - x)));

    track_angle = normalize (waypoint_angle - psi);
    along_track_distance = cos (radians(track_angle)) * waypoint_distance;
    cross_track_distance = - sin (radians(track_angle)) * waypoint_distance;

    port_rpm = k_propeller_hover * along_track_distance -
        k_surge_hover * u;
    stbd_rpm = k_propeller_hover * along_track_distance -
        k_surge_hover * u;

    if (TRUE)
    {
        printf ("HOVERCONTROL:\n");
        printf ("psi_command      = %5.1f, ", psi_command);
        printf ("x = %5.1f, y = %5.1f\n", x, y);
        printf ("waypoint_distance      = %5.1f, track_angle = %5.1f\n",
            waypoint_distance, track_angle);
        printf ("along_track_distance = %5.1f, ", along_track_distance);
        printf ("cross_track_distance = %5.1f\n", cross_track_distance);
        printf ("port_rpm / stbd_rpm = %5.1f\n", port_rpm);
    }
}

/* Simplified PD rudders/planes control rules: - - - - - */
delta_rudder = k_psi * normalize2 (psi - psi_command)
    + (k_r * r) + (k_v * v);

/* tanh not provided under OS-9 C, added at end of this program */
if (SLIDINGMODECOURSE == TRUE)
{
    sigma = k_sigma_r * r + k_sigma_psi * normalize2 (psi - psi_command);
}

```

```

    delta_rudder = (3.1403 * r) + 81.9712 * eta_steering * tanh (sigma);
}

depth_error = (z - z_command);

/* constrain depth_error to +/- 15.0 feet to prevent going vertical      */
/*      and enable stable pitch angle even on large depth changes          */
clamp (& depth_error, -15.0, 15.0, "depth_error");                        /* feet */

delta_planes = - (k_z * depth_error)
                + (k_theta * theta) + (k_q * q) - (k_w * w);

/* Dead stick means no open loop control of rudders/planes - - - - - */
if (DEADSTICKRUDDER)
{
    delta_rudder = rudder_command;
}
if (DEADSTICKPLANES)
{
    delta_planes = planes_command;
}

/* constrain planes & rudder orders +/- 40.0 degrees                    */
clamp (& delta_rudder, -40.0, 40.0, "delta_rudder");                    /* degrees */
clamp (& delta_planes, -40.0, 40.0, "delta_planes");                    /* degrees */

/* Send commands to rudders and planes **** */
rudder (delta_rudder);
planes (delta_planes);

/* Simplified lateral/vertical thruster control rules: - - - - - */
if (ROTATECONTROL == TRUE) /* open loop rotate thrusters */
{
    lateral_thruster_volts = k_thruster_rotate * rotate_command
                             * rotate_command;
}
else if (LATERALCONTROL == TRUE) /* open loop lateral thrusters */
{
    lateral_thruster_volts = - k_thruster_lateral * (lateral_command);
}
else /* heading control is default */
{
    lateral_thruster_volts = - k_thruster_psi * normalize2 (psi-psi_command)
                             - k_thruster_r * r;
}

vertical_thruster_volts = - k_thruster_z * (z - z_command)
                          - k_thruster_w * w;

if ((THRUSTERCONTROL) || (HOVERCONTROL == TRUE) || (ROTATECONTROL == TRUE))
{
    AUV_bow_vertical = vertical_thruster_volts;
    AUV_stern_vertical = vertical_thruster_volts;

    if (LATERALCONTROL == TRUE)
    {
        AUV_bow_lateral = lateral_thruster_volts; /* both positive, */
        AUV_stern_lateral = lateral_thruster_volts; /* same direction */
    }
}

```

```

else if (HOVERCONTROL == TRUE)
{
    AUV_bow_lateral    = - ( - k_thruster_psi*normalize2(psi-psi_command)
                           - k_thruster_r  * r)
                       + k_thruster_hover * cross_track_distance
                       + k_sway_hover      * v;

    AUV_stern_lateral  = ( - k_thruster_psi*normalize2(psi-psi_command)
                        - k_thruster_r    * r)
                      + k_thruster_hover * cross_track_distance
                      + k_sway_hover      * v;
}
else if ((THRUSTERCONTROL == TRUE) || (ROTATECONTROL == TRUE))
{
    AUV_bow_lateral    = - lateral_thruster_volts; /* negative */
    AUV_stern_lateral  =  lateral_thruster_volts;
}
else
{
    printf ("Thruster control logic error *** \n");
}

if (TRACE && DISPLAYSCREEN)
{
    printf ("Thruster control ON. Pre-clamp calculated values:\n");
    printf (" AUV_bow_vertical = %6.3f, AUV_stern_vertical = %6.3f\n",
            AUV_bow_vertical, AUV_stern_vertical);
    printf (" AUV_bow_lateral = %6.3f, AUV_stern_lateral = %6.3f\n",
            AUV_bow_lateral, AUV_stern_lateral);
}
else /* thrusters disabled */
{
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("Thruster control OFF. Pre-clamp calculated values:\n");
        printf ("vertical_thruster_volts = %6.3f\n",
                vertical_thruster_volts);
        printf (" lateral_thruster_volts = %6.3f\n",
                lateral_thruster_volts);
    }
    AUV_bow_vertical    = 0.0;
    AUV_stern_vertical  = 0.0;
    AUV_bow_lateral     = 0.0;
    AUV_stern_lateral   = 0.0;
}

if (TRACE && DISPLAYSCREEN)
{
    printf ("Pre-sqrt thruster control calculated values:\n");
    printf ("AUV_bow_vertical    = %6.3f\n", AUV_bow_vertical);
    printf ("AUV_stern_vertical   = %6.3f\n", AUV_stern_vertical);
    printf ("AUV_bow_lateral     = %6.3f\n", AUV_bow_lateral);
    printf ("AUV_stern_lateral    = %6.3f\n", AUV_stern_lateral);
}

/* convert to signed sqrt to account for volts-to-thrust relationship */
AUV_bow_vertical    = 2.0 * sqrt(6.0) * sign (AUV_bow_vertical )
                    * sqrt (fabs (AUV_bow_vertical ));
AUV_stern_vertical  = 2.0 * sqrt(6.0) * sign (AUV_stern_vertical)

```

```

                                * sqrt (fabs (AUV_stern_vertical));
AUV_bow_lateral    = 2.0 * sqrt(6.0) * sign (AUV_bow_lateral );
                                * sqrt (fabs (AUV_bow_lateral ));
AUV_stern_lateral  = 2.0 * sqrt(6.0) * sign (AUV_stern_lateral );
                                * sqrt (fabs (AUV_stern_lateral ));

if (TRACE && DISPLAYSCREEN)
{
    printf ("Post-sqrt thruster control calculated values:\n");
    printf ("AUV_bow_vertical    = %6.3f\n", AUV_bow_vertical);
    printf ("AUV_stern_vertical   = %6.3f\n", AUV_stern_vertical);
    printf ("AUV_bow_lateral     = %6.3f\n", AUV_bow_lateral);
    printf ("AUV_stern_lateral    = %6.3f\n", AUV_stern_lateral);
}

/* constrain thruster orders +/- 24.0 volts == 3820 rpm no-load          */
clamp (& AUV_bow_vertical, -24.0, 24.0, "AUV_bow_vertical");
clamp (& AUV_stern_vertical, -24.0, 24.0, "AUV_stern_vertical");
clamp (& AUV_bow_lateral, -24.0, 24.0, "AUV_bow_lateral");
clamp (& AUV_stern_lateral, -24.0, 24.0, "AUV_stern_lateral");

if ((port_rpm_command == 0.0) && (stbd_rpm_command == 0.0))
/* prevent planes chatter by zeroing them at zero speed                  */
{
    delta_rudder = 0.0;
    delta_planes = 0.0;
}

/* Normalization within bounds - - - - - */
delta_rudder = normalize2 (delta_rudder);
delta_planes = normalize2 (delta_planes);

/* constrain planes & rudder orders +- 40.0 degrees                      */
if (fabs (delta_rudder) > (40.0 /* degrees */))
{
    delta_rudder = (40.0) * (delta_rudder / fabs (delta_rudder));
}
if (fabs (delta_planes) > (40.0 /* degrees */))
{
    delta_planes = (40.0) * (delta_planes / fabs (delta_planes));
}

/* Send commands to rudders and planes *****/
rudder (delta_rudder);
planes (delta_planes);

/* Send command & get reply from sonar *****/
AUV_ST1000_bearing = 0.0;          /* relative bearings of sonar heads */
AUV_ST725_bearing  = 0.0;

/* send telemetry to tactical level and data recording files - - - */
record_data ();

/* read commands from tactical level - - - */
if (TACTICAL == TRUE) read_parallel_port ();

/* update simulation clock "t" - - - */
t = t + dt;

fflush (stdout);
currentloopclock = clock ();

```

```

if ((REALTIME == TRUE) && LOCATIONLAB &&
    (currentloopclock < previousloopclock
     + (int)(dt * (float) CLOCKS_PER_SEC)))
{
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("currentloopclock = %ld, previousloopclock = %ld\n",
                currentloopclock, previousloopclock);
        printf ("timestep dt = %5.3f seconds (corresponding clock ticks = %d)\n",
                dt, (int)(dt * (float) CLOCKS_PER_SEC));
        printf ("Busy wait until system clock reaches simulation clock, ");
        printf ("loop duration = %5.3f\n",
                ((float) currentloopclock - (float) previousloopclock)
                / CLOCKS_PER_SEC);
    }
    while (currentloopclock < previousloopclock
           + (int)(dt * (float) CLOCKS_PER_SEC))
    {
        currentloopclock = clock (); /* %%% busy wait %%% */
    }
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("Busy wait complete, loop+wait duration = %5.3f, ",
                ((float) currentloopclock - (float) previousloopclock)
                / CLOCKS_PER_SEC);
        printf ("current clock () = %ld\n", currentloopclock);
    }
}
else if ((REALTIME == FALSE) && LOCATIONLAB && DISPLAYSCREEN && TRACE)
{
    printf ("No busy wait, loop duration = %5.3f, ",
            ((float) currentloopclock - (float) previousloopclock)
            / CLOCKS_PER_SEC);
    printf ("current clock () = %ld\n", currentloopclock);
}
previousloopclock = clock ();

/* estimate X and Y by dead reckoning - - - - - */
x = x + (speed * dt * cos (radians (psi)));
y = y + (speed * dt * sin (radians (psi)));

if (!feof (auvscriptfile) && (t >= time_next_command)) /* all done */
{
    if (TRUE && DISPLAYSCREEN) printf ("end_test set TRUE\n");
    end_test = TRUE;
}
else if (t >= time_next_command) /* scriptfile not yet closed, read more */
{
    if (TRUE && DISPLAYSCREEN)
        printf ("\n[read more from parse_mission_script_commands]\n");
    parse_mission_script_commands (); /* get next script orders read */
}

if (TRACE && DISPLAYSCREEN)
    printf ("[finish closed_loop_control_module ()]\n");

return;

} /* end closed_loop_control_module () */

/*****
void get_control_constants ()
    /* get data from file at program start */
{
    if (TRACE && DISPLAYSCREEN)

```

```

printf ("[start get_control_constants ()]\n");

if (ENTERCONTROLCONSTANTS) /* - - - - - */
{
printf("Input start_dwell\n");
scanf("%d", &start_dwell);

/* note %F required by OS-9, accepted by SGI */
printf("Input k_psi, k_r, k_v\n");
scanf("%F %F %F", &k_psi, &k_r, &k_v);

printf("Input k_z, k_w, k_theta, and k_q\n");
scanf("%F %F %F %F", &k_z, &k_w, &k_theta, &k_q);

printf("Input k_thruster_psi,k_thruster_r\n");
scanf("%F %F", &k_thruster_psi, &k_thruster_r);

printf("Input k_thruster_rotate\n");
scanf("%F", &k_thruster_rotate);

printf("Input k_thruster_z,k_thruster_w\n");
scanf("%F %F", &k_thruster_z, &k_thruster_w);

printf("Input k_propeller_hover, k_surge_hover\n");
scanf("%F %F", &k_propeller_hover, &k_surge_hover);

printf("Input k_thruster_hover, k_sway_hover\n");
scanf("%F %F", &k_thruster_hover,
      &k_sway_hover);

printf("Input speed_limit from 1 to 2 feet/sec \n");
scanf("%F",&speed_limit);

printf("Input rpm from +-200.0 to +-700.0\n");
scanf("%F",&rpm);
}
else /* use default initialization values - - - - - */
{
if (TRACE && DISPLAYSCREEN)
printf ("[using default control constant values]\n");

start_dwell = 1; /* delay time in seconds */

k_psi = 1.00; /* degrees rudder per degree of course error */
k_r = 2.00; /* degrees rudder per degree/sec yaw rate */
k_v = 0.00; /* needed ?? */

k_z = 15.0; /* degrees planes per foot of depth error */
k_w = 2.0;
k_theta = 4.0;
k_q = 1.0;

rpm = 400.0;

k_thruster_psi = 0.6; /* volts per 1 degree course error */
k_thruster_r = 5.0;
k_thruster_rotate = 2.25; /* (24V)^2=> 2 # = 16.0 deg/sec empirical*/
/* k_thruster_rotate=(24V / 16 deg/sec)^2*/
k_thruster_lateral= 48.0; /* 24 V = 2 # = 0.5 ft/sec empirically */
/* note voltage follows a square law */
k_thruster_z = 50.0; /* guesses */
k_thruster_w = 50.0;

k_propeller_hover = 200.0; /* 200 rpm per one foot error */
k_surge_hover = 6000.0; /* 60 rpm per 0.01 foot/sec surge */
}

```

```

/* this value is high to reduce sternway */

k_thruster_hover = 4.0;
k_sway_hover = 40.0;

}
speed_limit = 2.0; /* 1.0 to 2.0 ft/sec */

if (TRACE && DISPLAYSCREEN)
{
    printf ("[k_psi = %5.2f, k_r = %5.2f, k_v = %5.2f, k_z = %5.2f, ",
            k_psi, k_r, k_v, k_z);
    printf ("k_w = %5.2f, k_theta = %5.2f, k_q = %5.2f]\n",
            k_w, k_theta, k_q);
    printf ("[k_thruster_psi = %5.2f, k_thruster_r = %5.2f, ",
            k_thruster_psi, k_thruster_r);
    printf ("k_thruster_rotate = %5.2f, ",
            k_thruster_rotate);
    printf ("k_thruster_z = %5.2f, k_thruster_w = %5.2f]\n",
            k_thruster_z, k_thruster_w);

    printf ("k_propeller_hover = %5.2f, k_surge_hover = %5.2f]\n",
            k_propeller_hover, k_surge_hover);

    printf ("k_thruster_hover = %5.2f, k_sway_hover = %5.2f]\n",
            k_thruster_hover, k_sway_hover);

    if (controlconstantsfile = fopen (CONTROLCONSTANTSFILENAME,"w")) == NULL)
    {
        printf("AUV execution: unable to open output file %s for writing. ",
            CONTROLCONSTANTSFILENAME);
        printf
        ("          Check ownership permissions in current directory.\n");
        printf("Exit.\n");
        exit (-1);
    }

    if (TRACE && DISPLAYSCREEN)
        printf ("[controlconstantsfile %s open, pointer = %x]\n",
            CONTROLCONSTANTSFILENAME, controlconstantsfile);

    fprintf (controlconstantsfile,
            "          \n\n");
    fprintf (controlconstantsfile,
            " AUV execution level control algorithm coefficients \n");
    fprintf (controlconstantsfile,
            "          \n\n\n");
    fprintf (controlconstantsfile,
            " k_psi k_r k_v k_z k_w k_theta k_q \n\n");
    fprintf (controlconstantsfile,
            " %5.2f %5.2f %5.2f %5.2f %5.2f %5.2f %5.2f \n\n\n",
            k_psi, k_r, k_v, k_z, k_w, k_theta, k_q );

    fprintf (controlconstantsfile,
            " k_thruster_psi k_thruster_r k_thruster_rotate\n\n");
    fprintf (controlconstantsfile,
            " %5.2f %5.2f %5.2f \n\n\n",
            k_thruster_psi, k_thruster_r, k_thruster_rotate);

    fprintf (controlconstantsfile,
            " k_thruster_z k_thruster_w \n\n");
    fprintf (controlconstantsfile,
            " %5.2f %5.2f \n\n\n",
            k_thruster_z, k_thruster_w);

    fprintf (controlconstantsfile,
            " k_propeller_hover k_surge_hover \n\n");

```

```

fprintf (controlconstantsfile,
        "      %5.2f      %5.2f      \n\n\n\n",
        k_propeller_hover, k_surge_hover);

fprintf (controlconstantsfile,
        "      k_thruster_hover      k_sway_hover \n\n");
fprintf (controlconstantsfile,
        "      %5.2f      %5.2f      \n\n\n\n",
        k_thruster_hover, k_sway_hover);

fflush (controlconstantsfile);
fclose (controlconstantsfile);

if (TRACE && DISPLAYSCREEN)
    printf ("[finish get_control_constants ()]\n");

return;

/* end get_control_constants () */

/*****/

double depth ()
{
    int    val    = 0;
    double new_z  = 0.0;
    double z_offset = 0.0;

    if (TRACE && DISPLAYSCREEN) printf ("[start depth ()]\n");

    if (LOCATIONLAB && DEADRECKON)
    {
        z = z_command;
    }

    if (NOT_YET_REIMPLEMENTED)
    {
        z_offset = 0.0;
        val      = adc2(0,0);
        new_z    = 0.002237 * (val - z_val0) + z_offset;    /* new_z (ft) */
    }
    else new_z = z;

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish depth (), returns %5.3f]\n", new_z);

    return (new_z);
} /* end depth () */

/*****/

double calculate_psi ()
{
    unsigned short psi_bit;
    int psi_bit_int, psi_bit_old_int, delta_psi_bit;
    double angle, tpi;
    double pi = 3.1415927;

    if (TRACE && DISPLAYSCREEN) printf ("[start calculate_psi ()]\n");

    if (LOCATIONLAB && DEADRECKON)
    {
        psi = psi_command;
    }

```

```

if (NOT_YET_REIMPLEMENTED)
{
    /* port needs to be redone: */
    psi_bit = Read_PortAB((struct MFI_PIA *) MFI_BASE);

    psi_bit &= 0x3FFF;
    psi_bit_int = psi_bit;
    psi_bit_old_int = psi_bit_old;

    delta_psi_bit = psi_bit_int - psi_bit_old_int;
    psi_bit_old = psi_bit;

    if(abs(delta_psi_bit) > 10000)
    {
        wrap_count = wrap_count - delta_psi_bit/abs(delta_psi_bit);
    }
    tpi = 2.0 * pi * wrap_count;

    angle = heading() - dg_offset + tpi;

    angle = degrees (angle);
} else angle = psi;

if (TRACE && DISPLAYSCREEN)
    printf ("[finish calculate_psi () returns %5.3f]\n", angle);

return (normalize (angle));
} /* end calculate_psi () */

/*****
void zero_gyro_Data ()
{
    int index;
    int save_trace;

    save_trace = TRACE;

    if (TRACE && DISPLAYSCREEN) printf ("[start zero_gyro_data ()]\n");

    pitch_0      = adc1(6);
    roll_0       = adc1(7);
    roll_rate_0  = adc1(9);
    pitch_rate_0 = adc1(8);
    yaw_rate_0   = adc1(10);
    z_val0       = adc2(0,0);
    dg_offset    = heading();

    if (TRACE && DISPLAYSCREEN)
        printf ("[device averaging for 2 seconds... ]\n");
    for (index=0;index<99;++index)
    {
        pitch_0      += adc1(6);
        roll_0       += adc1(7);
        roll_rate_0  += adc1(9);
        pitch_rate_0 += adc1(8);
        yaw_rate_0   += adc1(10);
        z_val0       += adc2(0,0);

        TRACE        = FALSE;
        dg_offset    += heading(); /* this is verbose if TRACEd */
        TRACE        = save_trace;
        tsleep (5);          /* 256ths of a second */
    }
}

```

```

    }

    pitch_0      = pitch_0/100;
    roll_0       = roll_0/100;
    roll_rate_0  = roll_rate_0/100;
    pitch_rate_0 = pitch_rate_0/100;
    yaw_rate_0   = yaw_rate_0/100;
    z_val0       = z_val0/100;
    dg_offset    = dg_offset/100.0;

    if (TRACE && DISPLAYSCREEN)
    {
        printf ("pitch_0      = %d\n", pitch_0);
        printf ("roll_0       = %d\n", roll_0);
        printf ("roll_rate_0  = %d\n", roll_rate_0);
        printf ("pitch_rate_0 = %d\n", pitch_rate_0);
        printf ("yaw_rate_0   = %d\n", yaw_rate_0);
        printf ("z_val0       = %d\n", z_val0);
        printf ("dg_offset    = %f\n", dg_offset);
    }

    if (TRACE && DISPLAYSCREEN) printf ("[finish zero_gyro_data ()]\n");

    return;

} /* end zero_gyro_data () */

/*****/

void initialize_dacs ()                /* Initialize all dac channels to zero */
{
    if (TRACE && DISPLAYSCREEN) printf ("[start initialize_dacs ()]\n");

    if (NOT_YET_REIMPLEMENTED)
    {
        control_surface (FRONT_RUD_TOP,0.0);
        control_surface (FRONT_RUD_BOT,0.0);
        control_surface (FRONT_PL_RIGHT,0.0);
        control_surface (FRONT_PL_LEFT,0.0);
        control_surface (REAR_RUD_TOP,0.0);
        control_surface (REAR_RUD_BOT,0.0);
        control_surface (REAR_PL_RIGHT,0.0);
        control_surface (REAR_PL_LEFT,0.0);

        main_motors_off ();
    }

    if (TRACE && DISPLAYSCREEN) printf ("[finish initialize_dacs ()]\n");

    return;

} /* end initialize_dacs */

/*****/

void initialize_adcs ()
{
    if (TRACE && DISPLAYSCREEN) printf ("[start initialize_adcs ()]\n");

    #if defined (sgi)
    #else
        /* Initialize MFI channels:  0 = input port, 1 = output port */

        Init_PortA ((struct MFI_PIA *) MFI_BASE, MFI_INPUT_PORT);
        Init_PortB ((struct MFI_PIA *) MFI_BASE, MFI_INPUT_PORT);
    #endif
}

```

```

        if (TRACE && DISPLAYSCREEN) printf ("[finish initialize_adcs ()]\n");
        return;
    } /* end initialize_adcs */

    /*****
void control_surface (surface, angle)

    /* This function sends the desired ANGLE to the specified control SURFACE
       The angle is first normalized to (-45 to 45), then correction is applied
       for the non-linearity in the servo control module */

    int    surface;

    double angle;

    {
        int volt;
        double a,b,c,d;

        if (FALSE && DISPLAYSCREEN) printf ("[start  control_surface ()]\n");
    if (NOT_YET_REIMPLEMENTED)
    {
        a = 1.2487e-4;
        b = -2.9087e-2;
        c = 5.0927;
        d = 500.6576;

        angle = angle*57.295779; /* Convert RADIANS to DEGREES */
        if ((angle < -22.92) || (angle > 22.92))
        {
            /* Plane saturated set to +- 45 */
            angle = 22.92*angle/fabs(angle);
        }

        volt = a*pow(angle,3.) + b*pow(angle,2.) + c*angle + d;
        dac2b(volt,surface);
    }

        if (FALSE && DISPLAYSCREEN) printf ("[finish control_surface ()]\n");
        return;
    } /* control_surface */

    /*****
void rudder (angle)

    /* Send angular deflection (RADIANS) to rudders.
       Convention (+) angle left turn, (-) angle right turn */

    double angle;

    {
        if (TRACE && DISPLAYSCREEN) printf ("[start  rudder ()]\n");

        control_surface (FRONT_RUD_TOP,-angle);
        control_surface (FRONT_RUD_BOT,angle);
        control_surface (REAR_RUD_TOP,angle);
        control_surface (REAR_RUD_BOT,-angle);
    }
    /*****/

```

```

    if (TRACE && DISPLAYSCREEN) printf ("[finish rudder ()]\n");
    return;
} /* rudder */
/*****/

void planes (angle)
/* Send angular deflection (RADIANS) to bow and stern planes.
Convention (+) angle dive, (-) angle rise */
{
    double angle;

    if (TRACE && DISPLAYSCREEN) printf ("[start planes ()]\n");

    control_surface (FRONT_PL_RIGHT,angle);
    control_surface (FRONT_PL_LEFT,-angle);
    control_surface (REAR_PL_RIGHT,-angle);
    control_surface (REAR_PL_LEFT, angle);

    if (TRACE && DISPLAYSCREEN) printf ("[finish planes ()]\n");
    return;
} /* end planes () */
/*****/

void main_motors_off () /* Turn off both main motors */
{
    if (TRACE && DISPLAYSCREEN) printf ("[start main_motors_off ()]\n");
    if (NOT_YET_REIMPLEMENTED)
    {
        dac1(512,SUPPLY);
        dac1(512,RIGHT_MOTOR);
        dac1(512,LEFT_MOTOR);

        if (TRACE && DISPLAYSCREEN) printf ("[finish main_motors_off ()]\n");
        return;
    }
} /* end main_motors_off () */
/*****/

void alive (interval, local_start_dwell)
{
    unsigned int interval;
    int local_start_dwell;

    {
        unsigned int iinterval,jinterval;
        double test_delta;

        if (TRACE && DISPLAYSCREEN) printf ("[start alive ()]\n");
    }
    if (NOT_YET_REIMPLEMENTED)
    {
        local_start_dwell = local_start_dwell*100;
        interval = interval*100;
        iinterval = local_start_dwell/interval;
        jinterval = 0;
        test_delta = .4; /* Deflect 22.5 degrees */
    }
}

```

```

while(jinterval < iinterval)
{
    control_surface (FRONT_RUD_TOP, test_delta);
    tsleep(interval); /* 256ths of a second */
    test_delta = -test_delta;
    jinterval = jinterval + 1;
}

tsleep(200); /* 256ths of a second */
}
if (TRACE && DISPLAYSCREEN) printf ("[finish alive ()]\n");
return;
}

/*****
void record_data_on ()
{
    if (TRACE && DISPLAYSCREEN) printf ("[start record_data_on ()]\n");
    /* Open files for writing */
    if ((auvdatafile = fopen (AUVDATAFILENAME, "w")) == NULL)
    {
        printf("AUV execution: unable to open output file %s for writing. ",
            AUVDATAFILENAME);
        printf
        ("          Check ownership permissions in current directory.\n");
        printf("Exit.\n");
        exit (-1);
    }
    if (TRACE && DISPLAYSCREEN)
        printf ("[auvdatafile %s open, pointer = %x]\n",
            AUVDATAFILENAME, auvdatafile);

    if ((auvtextfile = fopen (AUVTEXTFILENAME, "w")) == NULL)
    {
        printf("AUV execution: unable to open output file %s for writing. ",
            AUVTEXTFILENAME);
        printf
        ("          Check ownership permissions in current directory.\n");
        printf("Exit.\n");
        exit (-1);
    }
    if (TRACE && DISPLAYSCREEN)
        printf ("[auvtextfile %s open, pointer = %x]\n",
            AUVTEXTFILENAME, auvtextfile);

    fprintf (auvtextfile, "# auvtextfile %s shows state ", AUVTEXTFILENAME);
    fprintf (auvtextfile, "vector variables at one second intervals.\n\n");

    if (LOOPFOREVER)
        fprintf (auvtextfile, "# Mission replication %d\n",
            replication_count);

    /* testing code from wr2t1.c, not currently in use */
    /* serial.d is a telemetry test file to check connectivity */
    /* if ((serialtestfile = fopen ("serial.d", "r")) <= 0)
    {
        printf("AUV execution: record_data_on: can't open test file serial.d\n");
        printf("Exit.\n");
        exit (-1);
    }
    */
    if (TRACE && DISPLAYSCREEN) printf ("[finish record_data_on ()]\n");
}

```

```

    return;
}

/*****
void record_data_off ()

if (TRACE && DISPLAYSCREEN) printf ("[start record_data_off ()]\n");
if (TRACE && DISPLAYSCREEN)
{
    printf ("[flushing and closing auvdatafile %s %x]\n",
            AUVDATAFILENAME, auvdatafile);
    fflush (stdout);
}
if (auvdatafile != NULL)
{
    if (TRACE && DISPLAYSCREEN) printf ("[auvdatafile flushed]\n");
    fflush (stdout);
    fflush (auvdatafile);
    fclose (auvdatafile);
    if (TRACE && DISPLAYSCREEN) printf ("[auvdatafile closed]\n");
    fflush (stdout);
}
else if (TRACE && DISPLAYSCREEN) printf ("[auvdatafile was not open!!]\n");
if (TRACE && DISPLAYSCREEN)
{
    printf ("[flushing and closing auvtextfile %s %x]\n",
            AUVTEXTFILENAME, auvtextfile);
    fflush (stdout);
}
if (auvtextfile != NULL)
{
    if (TRACE && DISPLAYSCREEN) printf ("[auvtextfile flushed]\n");
    fflush (stdout);
    fflush (auvtextfile);
    fclose (auvtextfile);
    if (TRACE && DISPLAYSCREEN) printf ("[auvtextfile closed]\n");
    fflush (stdout);
}
else if (TRACE && DISPLAYSCREEN) printf ("[auvtextfile was not open!!]\n");
/* fclose (serialtestfile); /* serial port test file */
if (TRACE && DISPLAYSCREEN)
{
    printf ("[finish record_data_off ()]\n");
    fflush (stdout);
}
return;
}

*****/

void record_data ()
{
    /* temporary hold variables */

    double  AUV_time_temp,
            AUV_x_temp,      AUV_y_temp,      AUV_z_temp,
            AUV_phi_temp,    AUV_theta_temp,   AUV_psi_temp,
            AUV_u_temp,      AUV_v_temp,       AUV_w_temp,
            AUV_p_temp,      AUV_q_temp,       AUV_r_temp,
            AUV_x_dot_temp,  AUV_y_dot_temp,   AUV_z_dot_temp,

```



```

    AUV_ST725_strength = (AUV_ST725_strength_temp);
}
else if ((variables_parsed != 34) && (variables_parsed != -1))
{
    if (DISPLAYSCREEN)
    printf ("\nGarble problem in buffer_received !!! variables parsed = %d\n%s\n",
            variables_parsed, buffer_received);
    answer = getchar (); /* pause */
    TRACE = TRUE;
}

if (LOCATIONLAB == 0) speed = u; /* virtual world speed, not flow sensor */

if (TRACE && DISPLAYSCREEN)
    printf ("\nfrom virtual world buffer_received:\n%s", buffer_received);

if (TRUE && DISPLAYSCREEN)
{
    printf ("\nfrom virtual world state variables:");
    printf ("\n %s t=%5.3f x=%5.3f y=%5.3f z=%5.3f ",
            keyword, t,
            x, y, z);
    printf ("phi=%5.3f theta=%5.3f psi=%5.3f ",
            phi, theta, psi);
    printf ("u=%5.3f v=%5.3f w=%5.3f p=%5.3f q=%5.3f r=%5.3f ",
            u, v, w,
            p, q, r);
    printf ("x_dot=%5.3f y_dot=%5.3f z_dot=%5.3f ",
            x_dot, y_dot, z_dot);
    printf ("phi_dot=%5.3f theta_dot=%5.3f psi_dot=%5.3f ",
            phi_dot, theta_dot, psi_dot);
    printf ("delta_rudder=%5.3f delta_planes=%5.3f ",
            delta_rudder, delta_planes);
    printf ("port_rpm=%5.3f stbd_rpm=%5.3f ",
            port_rpm, stbd_rpm);
    printf ("bow_vertical=%5.3f stern_vertical=%5.3f ",
            AUV_bow_vertical, AUV_stern_vertical);
    printf ("bow_lateral=%5.3f stern_lateral=%5.3f ",
            AUV_bow_lateral, AUV_stern_lateral);
    printf ("ST1000 b/r/s %5.3f %5.3f %5.3f, ST725 b/r/s %5.3f %5.3f %5.3f",
            AUV_ST1000_bearing, AUV_ST1000_range, AUV_ST1000_strength,
            AUV_ST725_bearing, AUV_ST725_range, AUV_ST725_strength);
    printf (" [current time %d %d %d] \n",
            system_tmp->tm_hour, system_tmp->tm_min, system_tmp->tm_sec);
}

/* keep all telemetry variables in degrees */
phi = normalize2 (phi );
theta = normalize2 (theta);
psi = normalize (psi );
phi_dot = normalize2 (phi_dot);
theta_dot = normalize2 (theta_dot);
psi_dot = normalize2 (psi_dot);
p = normalize2 (p);
q = normalize2 (q);
r = normalize2 (r);
delta_rudder = normalize2 (delta_rudder);
delta_planes = normalize2 (delta_planes);

if (TRACE && LOCATIONLAB && DISPLAYSCREEN)
{
    printf ("-----\n");
}

if (auvdatafile != NULL) /* output data to telemetry file */
{
    if (buffer_size == 0) /* note that unmodified stream is saved */
        /* nothing was received, send auv_state */

```

```

        fprintf (auvdatafile, "%s", buffer);
    else
        /* feedback was received, send uvw_state */
        fprintf (auvdatafile, "%s", buffer_received);

    if (TRACE && DISPLAYSCREEN)
        printf("[printed to %s telemetry file]\n", AUVDATAFILENAME);

    /* only send/print out every 10th telemetry entry to tactical level */
    /* due to serial port bandwidth limitations :-( */

    /* redo this when clock logic is redone *****/
    if ((int)((t+0.05)*10.0) == (int) (t+0.05) *10)
    {
        if (TACTICAL && TRACE && DISPLAYSCREEN)
            printf ("[sending data to tactical level]\n");

#ifdef sgi
    else
        /* writeln (serialpath, buffer, 255); <<<<<<<<<<<< */
        if (TACTICAL == TRUE) write (serialpath, buffer, 255);
#endif

        if (TACTICAL && TRACE && DISPLAYSCREEN)
            printf ("[write buffer to tactical level serialpath OK]\n");

        if (auvtextfile != NULL) /* output data to .auv text file */
        {
            if (TRACE && DISPLAYSCREEN)
                printf ("[sending data to .auv text file]\n");

            fprintf (auvtextfile, "%s", buffer);
            if (buffer_size != 0) /* feedback was received, also send uvw_state */
                fprintf (auvtextfile, "%s", buffer_received);

            if (TRACE && DISPLAYSCREEN)
                printf ("[fprintf to .auv text file OK]\n");
        }

        telemetry_records_saved ++;

        if (((buffer_index +1) % FILEBUFFERSIZE) == 0) buffer_index = 0;
        else buffer_index ++;

        /* need to copy buffer to buffer_array if caching telemetry <<<<<<<<<<<< */
        if (TRACE && DISPLAYSCREEN) printf ("[buffer_index = %d]\n", buffer_index);

        /* ----- */
        /* test code to send data from file serial.d from wr2t1.c */
        /* read characters from file, echo characters to screen, */
        /* send characters to serialpath /t1 device */
        /* while ((c[0] = getc(serialtestfile)) != EOF) */
        {
            putc (c[0], stdout);
            writeln (serialpath, c, 1);
        }
        /* ----- */

        if (TRACE && DISPLAYSCREEN) printf ("[finish record_data ()]\n");

        return;
    }
}

```

```

/*****
double roll_angle ()      /* Return roll angle in RADIANS          */
{
    int    val;
    double angle = phi;    /* previous (or virtual world) value */

    if (TRACE && DISPLAYSCREEN) printf ("[start roll_angle ()]\n");

    if (NOT_YET_REIMPLEMENTED)
    {
        val = adc1(ROLL_ANGLE_CH);
        /* angle = ((516.578 - val)/5.7572)/57.295779; convert to radians */
        angle = (-.1737*val + .1737*roll_0)/57.295779;
    }

    angle = normalize2 (angle);

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish roll_angle () returns %5.3f]\n", angle);

    return (angle);
}

/*****
double pitch_angle ()     /* Return pitch angle in RADIANS        */
{
    int    val;
    double angle = theta;  /* previous (or virtual world) value */

    if (TRACE && DISPLAYSCREEN) printf ("[start pitch_angle ()]\n");

    if (NOT_YET_REIMPLEMENTED)
    {
        val = adc1(PITCH_ANGLE_CH);
        /* angle = ((520.153 - val)/8.340)/57.295779; convert to radians */
        angle = -((-0.1199*val + 0.1199*pitch_0)/57.295779);
    }

    angle = normalize2 (angle);

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish pitch_angle () returns %5.3f]\n", angle);

    return (angle);
}

/*****
double heading ()
{
    /* Return heading angle with respect to local magnetic north in radians
       from directional gyro */
    unsigned short dg_bit;
    double angle;

    if (TRACE && DISPLAYSCREEN) printf ("[start heading ()]\n");

    if (LOCATIONLAB && (DEADRECKON == FALSE))
    {
        angle = psi;
    }
    else if (LOCATIONLAB && (DEADRECKON == TRUE))

```

```

    {
        angle = psi_command;
    }
    else
    {
        if (NOT_YET_REIMPLEMENTED)
        {
            dg_bit = Read_PortAB(MFI_BASE);
            dg_bit &= 0x3FFF;
        }
        angle = (3.8350e-4) * dg_bit;
    }

    angle = normalize (angle);

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish heading () returns %5.3f]\n", angle);

    return (angle);
}

/*****
double roll_rate_gyro ()    /* Return roll rate in RADIANS/SEC          */
{
    int    val;
    double rate = p; /* previous (or virtual world) value */

    if (TRACE && DISPLAYSCREEN) printf ("[start roll_rate_gyro ()]\n");

#ifdef sgi
    val = adc1 (ROLL_RATE_CH);
    rate = (roll_rate_0/3.2113 - .31062*val)/57.295779;
#else
    rate = normalize2 (rate);

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish roll_rate_gyro () returns %5.3f]\n", rate);

    return (rate);
}

/*****
double pitch_rate_gyro ()    /* Return pitch rate in RADIANS/SEC      */
{
    int    val = 0;
    double rate = q; /* previous (or virtual world) value */

    if (TRACE && DISPLAYSCREEN) printf ("[start pitch_rate_gyro ()]\n");

#ifdef sgi
    val = adc1 (PITCH_RATE_CH);
    rate = (pitch_rate_0/13.69399 - .0730001*val)/57.295779;
#else
    rate = normalize2 (rate);

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish pitch_rate_gyro () returns %5.3f]\n", rate);

    return (rate);
}

```

```

/*****/
double yaw_rate_gyro ()      /* Return yaw rate in RADIANS/SEC          */
{
    int    val = 0;
    double rate = r; /* previous (or virtual world) value */

    if (TRACE && DISPLAYSCREEN) printf ("[start yaw_rate_gyro ()]\n");

    #if defined (sgi)
    #else
        val = adc1(YAW_RATE_CH);
        rate = (yaw_rate_0/13.653216 - .0732362*val)/57.295779;
    #endif

    rate = normalize2 (rate);

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish yaw_rate_gyro () returns %5.3f]\n", rate);

    return (rate);
}

/*****/
double stbd_motor_rpm ()      /* Reads rpm from RIGHT_MOTOR          */
{
    int    pulse;
    double local_stbd_rpm;

    if (TRACE && DISPLAYSCREEN) printf ("[start stbd_motor_rpm ()]\n");

    pulse = adc1(RIGHT_MOTOR_RPM);
    local_stbd_rpm = 1.244*pulse - 8.4792;

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish stbd_motor_rpm () returns %5.3f]\n", stbd_rpm);

    return (local_stbd_rpm);
}

/*****/
double port_motor_rpm ()      /* Reads rpm from LEFT_MOTOR          */
{
    int    pulse;
    double local_port_rpm;

    if (TRACE && DISPLAYSCREEN) printf ("[start port_motor_rpm ()]\n");

    pulse = adc1(LEFT_MOTOR_RPM);
    local_port_rpm = 1.244*pulse - 8.4792;

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish port_motor_rpm () returns %5.3f]\n", local_port_rpm);

    return (local_port_rpm);
}

/*****/
double get_speed () /* Filter the speed signal          */
{
    int    index;
    double avg_speed = 0.0;

    if (TRACE && DISPLAYSCREEN)
        printf ("[start get_speed (), LOCATIONLAB=%d]\n", LOCATIONLAB);
}

```

```

if (LOCATIONLAB)
{
    if (TRACE && DISPLAYSCREEN)
        printf ("[finish get_speed () returns *");
    avg_speed = (speed_per_rpm * (port_rpm + stbd_rpm) / 2.0);
    if (TRACE && DISPLAYSCREEN)
        printf ("%5.3f]\n", avg_speed);

    return (avg_speed);
}
else
{
    speed_array[pointer] = adc2(1,0);
    for (index=0;index<11;++index)
    {
        avg_speed += speed_array[index];
    }
    avg_speed = avg_speed/11;
    avg_speed = avg_speed * 0.003635;
    if (avg_speed < 0.78)
    {
        if (t < 10.0)
        {
            avg_speed = speed + 0.000045*(rpm-150);
            if (avg_speed > (rpm*0.002)) avg_speed = rpm*0.002;
        }
        else
        {
            avg_speed = 1.0;
        }
        if(t < 2.0) avg_speed = 0.0;
    }
    pointer = pointer + 1;
    if (pointer > 10) pointer = 0;
}

if (TRACE && DISPLAYSCREEN)
    printf ("[finish get_speed () returns %5.3f]\n", avg_speed);

return (avg_speed);
}
/*****/

void get_init_avg ()
{
    int index, rng_sum;

    if (TRACE && DISPLAYSCREEN) printf ("[start get_init_avg ()]\n");

    rng_sum = 0;
    range_index = 0;

    for(index = 0; index < AVG_PTS; ++index)
    {
        via0[ORB_IRB] = (SONAR_SW1 & SONAR_SW3) | SONAR_TRIG2;
        via0[ORB_IRB] = SONAR_SW1 & SONAR_SW3;
        tsleep(5);
        range = adc2(3,0);

        rng_sum += range;
        range_array[index] = range;
        ++range_index;
    }
    avg_rng = (rng_sum/AVG_PTS) * 1.0;

    if (TRACE && DISPLAYSCREEN) printf ("[finish get_init_avg ()]\n");
}

```

```

    return;
}

/*****
void get_avg_rng ()
{
    int index, UPDATE_AVG, int_rng_sum;

    if (TRACE && DISPLAYSCREEN) printf ("[start  get_avg_rng ()]\n");

    UPDATE_AVG = 0;
    int_rng_sum = 0;

    if (((float)range > avg_rng ) ||
        (fabs((float)range - avg_rng) <= MAX_RNG_DIFF) ||
        (bad_rng >= MAX_BAD_PTS))
    {
        range_array[range_index] = range;
        ++range_index;
        UPDATE_AVG = 1;
        if(bad_rng > MAX_BAD_PTS)
        {
            ++bad_updates;
        }
        if(bad_updates >= MIN_NC_PTS)
        {
            bad_rng = 0;
        }
    }
    else
    {
        ++bad_rng;
    }

    if(UPDATE_AVG)
    {
        for(index = range_index - AVG_PTS; index <= range_index; ++index)
        {
            int_rng_sum += range_array[index];
        }

        avg_rng = int_rng_sum/AVG_PTS * 1.0;
    }
    if (TRACE && DISPLAYSCREEN) printf ("[finish get_avg_rng ()]\n");

    return;
}

/*****
/*
Hardware control changes *FOLLOWING* hardware upgrade 1993:

Telemetry to tactical level:      serial port /T1 via driver /TT
Orders from tactical level:      parallel port /P via MFI register A
Sonar:                            interface card device driver /T3

*/
/*****/

void open_device_paths ()
{
    if (TRACE && DISPLAYSCREEN) printf ("[start  open_device_paths ()]\n");
#ifdef (sgi)

```



```

    }
    else if (next_char != 10)          /* LF ignored, others appended */
    {
        current_command [index] = next_char;
        index ++;
        if (PARALLELPORTTRACE && DISPLAYSCREEN)
        {
            /* print character to screen */
            printf ("\n %c = %2x, PortAFlag after reading = %4x]  ",
                    next_char, next_char, PortAFlag);
        }
    }
} /* end while loop to read characters from port */

if (PARALLELPORTTRACE && DISPLAYSCREEN)
{
    printf("    [%c = %2x, PortAFlag = %2x, exiting read_parallel_port ()]",
           next_char, next_char, PortAFlag);
}
#endif

if (TRACE && DISPLAYSCREEN) printf ("[finish read_parallel_port ()]\n");
return;
} /* end read_parallel_port */

/*****
/* Card arrangement in AUV *PRIOR* to hardware upgrade 1993:

-----
|           | |           | |           MFI           | <-- Direct
|           | |           | |           Reg A and B    | Gyro
-----

-----
|           |           |           |           | <-- Sonars
|           |           |           |           | ( 0 - 15 )
-----

Main motors --> -----
|           |           |           |           |           | <-- Gyros
|           |           |           |           |           | ( 0 - 15 )
-----

-----
|           |           |           |           | <-- Planes
|           |           |           |           | ( 0 - 7 )
-----

This file contains the functions which address the A/D D/A cards
directly in terms of voltages. */

/*****
* dac1(s,ch) -- writes signal 's' to ada-1 dac channel 'ch'
*              (allowable channels 0-3)
*****/
void dac1(s,ch)
int s,ch;
{
if (NOT_YET_REIMPLEMENTED)
{
    ch = ch << 2;
/* offset for G-96 addressing */

```

```

        dac1_a[ch] = s >> 2;          /* write upper 8 bits to MSB */
        dac1_a[ch + DAC_LSB_OFFSET] = s << 6; /* write lower 2 bits B3,B2 */
    }
    return;
} /* dac1 */

/*****
 * dac2b(s,ch) -- writes signal 's' to dac2b dac channel 'ch'
 *                (allowable channels 0-15)
 *****/

void dac2b(s,ch)
int s,ch;
{
    if (NOT_YET_REIMPLEMENTED)
    {
        ch = ch << 2;
        dac2b_a[ch] = s >> 2;          /* offset for G-96 addressing */
        dac2b_a[ch + DAC_LSB_OFFSET] = s << 6; /* write upper 8 bits to MSB */
        /* write lower 2 bits B3,B2 */
    }
    return;
} /* dac2b */

/*****
 * adc1(n) -- reads ada-1 adc channel 'n' (channels 0-15)
 *****/
int adc1(n)
int n;
{
    int val;

    if (NOT_YET_REIMPLEMENTED)
    {
        adc1_a[ADC1_CMD_REG] = n;
        while (adc1_a[ADC1_STATUS_REG] > 20); /* wait for data */
        val = adc1_a[ADC1_MSB] << 2;
        val += adc1_a[ADC1_LSB] >> 6;
        return (val);
    }
    else return (0);
} /* adc1 */

/*****
 * adc2(n,g); -- Reads adc-2 channel 'n' (0-15)
 *                with gain 'g' (0 to F => 0 - 1024)
 *****/

int adc2(n,g)
int n,g;
{
    int val;

    if (NOT_YET_REIMPLEMENTED)
    {
        adc2_a[ADC2_CH_GAIN] = (n << 4) | g; /* set c&g, start conv */
        while((adc2_a[ADC2_STATUS_REG] & 0x7) != 0); /* wait for ready */

        /* This adc uses 0 - 4095 to represent full scale input, in order
        to write to the dac (which uses 0 -1023 for full scale) you
        must divide val by 4 or shift right by 2. Use the next line to
        get full resolution.
        val = adc2_a[ADC2_DATA];
        The next line is used for testing purposes only

        val = adc2_a[ADC2_DATA] >> 2; */
    }
}

```

```

        val = adc2_a[ADC2_DATA];
        val = val & 0x0FFF;

        return val;
    } else return (0);
    /* adc2 */

/*****
/*
The program code for the Multi-Function Interface originated from 'mfi.c'
Routines include Init_PortA, Init_PortB, Read_PortA, Read_PortB, Read_PortAB

Excerpt of 'mfi.c' comments follows:

    Program example for the Multi-Function-Interface (MFI)
    This example uses the 6821 PIA on the MFI board
    General purpose functions are provided to initialize the PIA
    and read/write data to the ports

    MFI P2 connector definitions are provided by the GESMFI-1 data
    sheet available from GESPAC, Inc.

    6821 device specifics are covered in the 8-bit microprocessor
    & peripheral data book from Motorola Inc.

    3/1/91          J. Rawlins          RealTime Software Consulting

*/
/*****
/*
    * Init_PortA(base, dir) -- Initialize Port A of MFI
    *                         dir: 1 = output port, 0 = input port
    *****/

void Init_PortA (base, dir)
    register struct MFI_PIA *base; /* base address of MFI board on G96 bus */
    int dir;                       /* direction: 1 = output port, 0 = input port */
{
    register short temp;
    temp = base->cra; /* save contents of control reg. (no-op) */
    base->cra = 0x00; /* select: b2 = 0 data direction reg. */
    base->pra = 0x00; /* set portA: 0 = input */
    base->cra = 0x24; /* select: access data reg.s (b2=1) */
    /* b5=1,b4=0,b3=0(read w/cal restore) */
} /* Init_PortA */

/*****
/*
    * Init_PortB(base, dir) -- Initialize Port B of MFI
    *                         dir: 1 = output port, 0 = input port
    *****/

void Init_PortB (base, dir)
    register struct MFI_PIA *base; /* base address of MFI board on G96 bus */
    int dir;                       /* direction: 1 = output base, 0 = input base */
{
    register short temp;

    temp = (base->crb & 0x00FF); /* get current value of control A */
    temp &= ~4; /* clear bit #2 so we can access ddra */
    base->crb = temp;
    if ( dir ) /* make port B all outputs */
        base->prb = 0x00FF; /* port B is all inputs */
    else

```

```

        base->prb = 0x0000;
        temp |= 4; /* set bit #2 to access data registers */
        base->crb = temp;
    } /* Init_PortB */

    /******
     * Read_PortA (base) -- returns 8 bit value from port A
     *
     * *****/

unsigned char Read_PortA (base)
register struct MFI_PIA *base; /* base address of MFI */
{
    register unsigned short temp;
    temp = base->pra; /* read data reg.should reset busy */
    return(temp & 0x00FF); /* return data to calling program */
}

    /******
     * Read_PortB (base) -- returns 8 bit value from port B
     *
     * *****/

unsigned char Read_PortB (base)
register struct MFI_PIA *base; /* base address of MFI */
{
    register unsigned short temp;
    temp = base->prb;
    return(temp & 0x00FF);
}

    /******
     * Read_PortAB (base) -- return a 16 bit value from ports
     * A and B combined then mask off
     * the 15 th and 16 th bits.
     * Note: PIA PA0-PA7 is the LSB and PB0-PB7 the MSB
     * *****/

unsigned short Read_PortAB (base)
register struct MFI_PIA *base; /* base address of MFI */
{
    register unsigned short hi,lo,temp;

    lo = (base->pra & 0x00FF); /* get least significant byte from A */
    hi = (base->prb & 0x00FF); /* and most significant byte from B */
    temp = ((hi << 8) + lo); /* shift hi into upper byte of word */
    return ( temp ); /* return data */
}

    /******

void set_bsyA(base) /* sets CB2 high (for busy to sending port) */
register struct MFI_PIA *base; /* base address of MFI */
{
    register short temp;
    temp = (base->cra & 0xFF); /* save cra values */
    base->cra = 0x38; /* 8 bit 1= CR2 high */
    base->cra = temp; /* restore cra values */
}

/* sets CB2 low (for -busy to sending port) */
void rst_bsyA(base)
register struct MFI_PIA *base; /* base address of MFI */
{
    register short temp;

```

```

    temp = (base->cra & 0xFF); /* save cra values */
    base->cra = 0x30;          /* 8 bit 0= CR2 low */
    base->cra = temp;          /* restore cra values */

int ck_sta (base)
register struct MFI_PIA *base; /* base address of MFI */
{
    register unsigned short temp;
    temp = base->cra;          /* save cra values */
    return (temp);
}

/*****

void center_sonar ()
{
    int direction,encoder_width;
    char encode;

    if (! SONARINSTALLED)
    {
        printf ("[start/stop center_sonar, SONARINSTALLED false]\n");
        return;
    }

    if (TRACE && DISPLAYSCREEN) printf ("[start center_sonar ()]\n");

    encoder_width = 0;
    direction = 1;

    /* set_step_size('H'); */          /* '1' = 0.9, '2' = 1.8, '4' = 3.6 */

    /* Are we inside the Encoder Sensor ? */
    encode = query_sonar_1_reply ('M'); /* Test Head Direction (No Step) */
    if (SONARTRACE && DISPLAYSCREEN)
        printf("center_sonar: encode = %c\n",encode);

    if ((encode == 't') || (encode == 'T'))
    {
        while( (encode == 't') || (encode == 'T') )
        {
            encode = query_sonar_1_reply ('+'); /* Index Sonar '+' direction */
        }

        /* Outside Encoder Sensor Now */
        direction = -1; /* Reverse Sonar Rotation to Establish Encoder Width */
    }

    while( (encode == 'f') || (encode == 'F') )
    {
        if(direction == 1)
        {
            encode = query_sonar_1_reply ('+'); /* Index Sonar '+' direction */
            if (SONARTRACE && DISPLAYSCREEN) printf("%c\n",encode);
        }
        else
        {
            encode = query_sonar_1_reply ('-'); /* Index Sonar '-' direction */
        }
    }

    /* Found Edge of Encoder */
    while( (encode == 't') || (encode == 'T') )
    {
        encoder_width = encoder_width + 1;

        if(direction == 1)

```



```

    }
    reply = xx[0];

    if (TRACE && DISPLAYSCREEN)
        printf ("[finish query_sonar_1_reply () returns %c]\n", reply);

    return (reply);
}

/*****/
void set_step_size (step_code)

    char step_code;
{
    unsigned int n;
    char      reply;

    if (! SONARINSTALLED)
    {
        printf ("[start/stop set_step_size (), SONARINSTALLED false]\n");
        return;
    }

    if (TRACE && DISPLAYSCREEN) printf ("[start  set_step_size ()]\n");

    if (SONARTRACE && DISPLAYSCREEN) printf ("step code = %c\n", step_code);
    write (sonarpath, step_code, 1);
    tsleep (1); /* 256ths of a second */

    n = read (sonarpath, reply, 1); /* n unused????? */

    if (SONARTRACE && DISPLAYSCREEN) printf ("step = %c\n", reply);

    if (TRACE && DISPLAYSCREEN) printf ("[finish set_step_size ()]\n");

    return;
}

/*****/
void tty_mode (tty_mode_path, mode)

    int  tty_mode_path;
    int  mode;          /* note type specifications differ from headtest.c */
{
    static struct sgbuf old, new;
    static int init = 1;
    int status;

    if (! SONARINSTALLED)
    {
        if (TRACE && DISPLAYSCREEN)
            printf ("[start/stop tty_mode, SONARINSTALLED false ()]\n");
        return;
    }

    if (init)
    {
        if (TRACE && DISPLAYSCREEN) printf ("[start  tty_mode ()]\n");

        init = 0;
        status = _gs_opt(tty_mode_path, &old);
        status = _gs_opt(tty_mode_path, &new);

        new.sg_class = 0;
    }
}

```

```

        new.sg_case      = 0;
        new.sg_backsp    = 0;
        new.sg_delete    = 0;
        new.sg_echo      = 0;
        new.sg_alf       = 0;
        new.sg_nulls     = 0;
        new.sg_pause     = 0;
        new.sg_page      = 0;
        new.sg_bspch     = 0;
        new.sg_dlnch     = 0;
        new.sg_eorch     = 0;
        new.sg_eofch     = 0;
        new.sg_rlnch     = 0;
        new.sg_dulnch    = 0;
        new.sg_psch      = 0;
        new.sg_kbich     = 0;
        new.sg_kbach     = 0;
        new.sg_bsech     = 0;
        new.sg_bellch    = 0;
        new.sg_parity    = 0;
        new.sg_tabcr     = 0;
        new.sg_tabsiz    = 0;
        new.sg_ttbl      = 0;
        new.sg_col       = 0;
        new.sg_err       = 0;
    }

    if (mode) _ss_opt (tty_mode_path, &new);
    else      _ss_opt (tty_mode_path, &old);

    if (TRACE && DISPLAYSCREEN) printf ("[finish tty_mode ()]\n");

    return;
}

/*****

void print_valid_keywords ()
{
    printf ("\n");
    printf ("          [help] [trace|notrace] [loopforever|looponce]\n");
    printf ("          [wait #] [time #] [timestep (0.0..5.0)] [mission]\n");
    printf ("          [keyboard|keyboard-off] [quit] [kill]\n");
    printf ("          [rpm] [course] [depth] [thrusters|thrusters-off]\n");
    printf ("          [loopfilebackup] [entercontrolconstants]\n");
    printf ("          [rotate] [position] [orientation]\n");
    printf ("          [sonartrace|sonartraceoff] [sonarinstalled]\n");
    printf ("          [trace|trace-off] [parallellporttrace] \n");
    printf ("          [remotehost hostname] [realtime|nopause] [pause]\n");
    printf ("          [loop-forever|loop-once] [entercontrolconstants]\n");
    printf ("          [silence] [e-mail|no-email] [waypoint]\n");
    printf ("See ~/execution/mission.script.HELP for command syntax details.\n");
    printf ("\n");

    #if defined(sgi)
        printf ("popping up 'mission.script.HELP' as a zip file...\n");
        system ("zip -v ~/execution/mission.script.HELP");
    #endif

    return;
} /* end print_valid_keywords */

*****/

void open_virtual_world_socket () /* see os9sender.c for original code */

```



```

if (virtual_world_socket_opened == FALSE)
{
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("[virtual_world_socket_opened FALSE,");
        printf (" shutdown_virtual_world_socket ignored]\n");
    }
    return;
}
if (TRACE && DISPLAYSCREEN)
    printf ("[shutdown_virtual_world_socket start ...]\n");

/* No need to send a message to other side that bridge is going down, */
/* since SIGPIPE signal trigger may shutdown server on other side */

if (close (socket_stream) == -1)
{
    if (TRACE && DISPLAYSCREEN)
        printf ("shutdown_virtual_world_socket close (socket_stream) failed\n");

    /* shutdown () reference: "Using OS-9 Internet" manual p. 2-55 */

    if (shutdown (socket_stream, 2) == -1)
    {
        if (TRACE && DISPLAYSCREEN)
        {
            printf ("[shutdown_virtual_world_socket shutdown");
            printf (" (socket_stream, 2) failed]\n");
        }

        kill_return_value = kill (socket_stream, SIGKILL);

        if (TRACE && DISPLAYSCREEN)
        {
            printf ("[shutdown_virtual_world_socket kill (socket_stream,");
            printf (" SIGKILL) returned %d]\n", kill_return_value);
        }
    }
}

if (TRACE && DISPLAYSCREEN)
    printf ("[shutdown_virtual_world_socket return]\n");

return;
} /* end shutdown_virtual_world_socket () */

/*****

void send_data_on_virtual_world_socket ()/* see os9sender.c for original code */
{
    bytes_left      = socket_length;
    bytes_written   = 0;
    ptr_index       = buffer; /* this global string is the data to be sent */

    if (virtual_world_socket_opened == FALSE)
    {
        return;
    }
    if (TRACE && DISPLAYSCREEN)
        printf ("[send_data_on_virtual_world_socket start ...]\n");

    while ((bytes_left > 0) && (bytes_written >= 0)) /* write loop *****/
    {
        bytes_sent = write (socket_stream, ptr_index, bytes_left);

        if (bytes_sent < 0) bytes_written = bytes_sent;
        else if (bytes_sent > 0)

```



```

        ptr_index      += bytes_read;
    }
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("[get_stream_from_virtual_world_socket receiver block");
        printf (" loop bytes_read = %d]\n", bytes_read);
    }
    /* if nothing is waiting to be read, break out of read loop          */
    if ((bytes_read == 0) && (bytes_received == 0)) break;
}
if (bytes_received < 0)      /* failure      */
{
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("[get_stream_from_virtual_world_socket receiver block read");
        printf (" failed, bytes_received = %d]\n", bytes_received);
    }
}
else if (bytes_received == 0) /* no transfer */
{
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("[get_stream_from_virtual_world_socket received 0 bytes!!]\n");
    }
}
else if (bytes_received > 0) /* success      */
{
    if (TRACE && DISPLAYSCREEN)
    {
        printf ("[get_stream_from_virtual_world_socket received %d bytes]\n",
                bytes_received);
    }
}

/* Check termination *****/
if (strncmp (buffer_received, "shutdown", 8) == 0)
{
    if (TRACE && DISPLAYSCREEN) printf
        ("[get_data_on_virtual_world_socket: shutdown_signal_received]\n");
    shutdown_virtual_world_socket ();
}
if (TRACE && DISPLAYSCREEN)
    printf ("[get_stream_from_virtual_world_socket return]\n");

return;
} /* end get_stream_from_virtual_world_socket () */

/*****/
double degrees (rads)      /* radians input */
{
    double rads;
    return rads * 180.0 / PI;
}
/*****/
double radians (degs)      /* degrees input*/
{
    double degs;
    return degs * PI / 180.0;
}
/*****/
double normalize (degs)     /* degrees input*/

```

```

        double degs;
    {
        double result = degs;

        while (result < 0.0) result += 360.0;
        while (result >= 360.0) result -= 360.0;

        return result;
    }
    /*****/

double normalize2 (degs)      /* degrees input*/
    double degs;
{
    double result = degs;

    while (result <= -180.0) result += 360.0;
    while (result > 180.0) result -= 360.0;

    return result;
}
/*****/

double radian_normalize (rads)      /* radians input*/
    double rads;
{
    double result = rads;

    while (result < 0.0) result += 2.0 * PI;
    while (result >= 2.0 * PI) result -= 2.0 * PI;

    return result;
}
/*****/

double radian_normalize2 (rads)      /* radians input*/
    double rads;
{
    double result = rads;

    while (result <= -PI) result += 2.0 * PI;
    while (result > PI) result -= 2.0 * PI;

    return result;
}
/*****/

void clamp (clampee, absolute_min, absolute_max, name)
    double * clampee;
    double absolute_min;
    double absolute_max;
    char * name;
{
    double new_value, local_min, local_max;

    if ((absolute_max == 0.0) && (absolute_min == 0.0)) return;      /* no clamp */
    if (absolute_max >= absolute_min) /* ensure min & max used in proper order */
    {
        local_min = absolute_min;
        local_max = absolute_max;
    }
    else
    {
        local_min = absolute_max;
        local_max = absolute_min;
    }
}

```

```

if ((* clampee) > local_max)
{
    new_value = local_max;

    if (TRACE && DISPLAYSCREEN)
        printf ("[clamping %s from %5.3f to %5.3f]\n",
                name, * clampee, new_value);

    * clampee = new_value;
}
if ((* clampee) < local_min)
{
    new_value = local_min;

    if (TRACE && DISPLAYSCREEN)
        printf ("[clamping %s from %5.3f to %5.3f]\n",
                name, * clampee, new_value);

    * clampee = new_value;
}
}
...../
#ifdef sgi
#else

/* thanks to Michael Olberg    Oct 20, 94    olberg@bele.oso.chalmers.se    */
double atan2(y, x)
    double y; double x;
{
    if (TRACE && DISPLAYSCREEN)
        printf ("[atan2 (%5.3f, %5.3f)]\n", y, x);

    if (x == 0.0) {
        if (y > 0.0)    return(-PI/2.0);
        else           return( PI/2.0);
    } else {
        if (x < 0.0) {
            if (y < 0.0) return(atan(y/x)-PI);
            else        return(atan(y/x)+PI);
        } else
            return(atan(y/x));
    }

    /* as to the tanh you will simply have to use */
}

double sinh(x)
    double x;
{
    return (exp(x) - exp(-x))/2.0;
}

double cosh(x)
    double x;
{
    return (exp(x) + exp(-x))/2.0;
}

double tanh(x)
    double x;
{
    return sinh(x)/cosh(x);
}

#endif

...../

```

```

double sign (x)
    double x;
{
    if      (x > 0.0) return  1.0;
    else if (x < 0.0) return -1.0;
    else      return  0.0;
}

/*****
/*****
/* end of execution.c */
/*****
/*****/

```

D. *parse_functions.c* Tactical Script Command Parse Functions

```
/*
*****
Program:      parse_functions.c
Authors:      Don Brutzman
Revised:      28 October 94
System:       AUV Gespac 68020/68030, OS-9 version 2.4
Compiler:     Gespac cc Kernighan & Richie (K&R) C

Compilation:  ftp>      put parse_functions.c
               auvsim1> chd execution
               [68020]   auvsim1> make -k2f execution
               [68030]   auvsim1> make      execution

               [Irix ]   fletch> make execution

Purpose:      Reduce size of execution.c to allow OS-9 C compiler to work
*/

/* parse_functions.c */

#include "globals.h"
#include "defines.h"

void      parse_command_line_flags      ();
void      parse_mission_script_commands ();
void      parse_mission_string_commands ();

extern void print_valid_keywords      ();
extern void send_data_on_virtual_world_socket ();
extern void get_control_constants     ();
extern void clamp                     ();

/*
*****
void parse_command_line_flags (argc, argv)

int argc; char **argv;      /* command line arguments */
{
    int index;

    if (DISPLAYSCREEN)
    {
        printf ("[parse_command_line_flags start: # arguments = %d]\n", argc);
        for (i = 0; i < argc; i++) printf (" %s", argv[i]);
        printf (" ]\n");
    }

    if (DISPLAYSCREEN) printf ("[parse arguments:  ");
    {
        for (i = 1; i < argc; i++)
        {
            printf ("%s ", argv[i]);

            for (index = 0; index <= (int)strlen (argv[i]); index++)/* uppercase */
                argv[i] [index] = toupper (argv[i] [index]);
        }
        printf (" ]\n");
    }
}
*****
*/
```

```

}
strcpy (buffer, ""); /* initialize for SILENT */
for (i = 1; i < argc; i++)
{
    if ((strcmp (argv[i], "HELP") == 0) ||
        (strcmp (argv[i], "?") == 0) ||
        (strcmp (argv[i], "/?") == 0) ||
        (strcmp (argv[i], "-?") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[print_help] ");
        print_help = TRUE;
    }
    else if ((strcmp (argv[i], "KEYBOARD") == 0) ||
             (strcmp (argv[i], "KEY-BOARD") == 0) ||
             (strcmp (argv[i], "KEYBOARD-INPUT") == 0) ||
             (strcmp (argv[i], "KEYBOARDINPUT") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[KEYBOARDINPUT = TRUE] ");
        KEYBOARDINPUT = TRUE;
    }
    else if (strcmp (argv[i], "TRACE") == 0)
    {
        if (TRACE && DISPLAYSCREEN) printf ("[TRACE = TRUE] ");
        TRACE = TRUE;
    }
    else if ((strcmp (argv[i], "TRACEOFF") == 0) ||
             (strcmp (argv[i], "TRACE-OFF") == 0) ||
             (strcmp (argv[i], "NOTRACE") == 0) ||
             (strcmp (argv[i], "NO-TRACE") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[TRACE = FALSE] ");
        TRACE = FALSE;
    }
    else if ((strcmp (argv[i], "LOOPFOREVER") == 0) ||
             (strcmp (argv[i], "LOOP-FOREVER") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[LOOPFOREVER] ");
        LOOPFOREVER = TRUE;
    }
    else if ((strcmp (argv[i], "LOOPONCE") == 0) ||
             (strcmp (argv[i], "LOOP-ONCE") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[LOOPONCE] ");
        LOOPFOREVER = FALSE;
    }
    else if ((strcmp (argv[i], "LOOPFILEBACKUP") == 0) ||
             (strcmp (argv[i], "LOOP-FILE-BACKUP") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[LOOPFILEBACKUP] ");
        LOOPFILEBACKUP = TRUE;
    }
    else if ((strcmp (argv[i], "ENTERCONTROLCONSTANTS") == 0) ||
             (strcmp (argv[i], "ENTER-CONTROL-CONSTANTS") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[ENTERCONTROLCONSTANTS] ");
        ENTERCONTROLCONSTANTS = TRUE;
    }
    else if ((strcmp (argv[i], "TACTICAL") == 0) ||
             (strcmp (argv[i], "TACTICAL-ON") == 0))
    {
        printf ("%s\n", argv[i]);
        TACTICAL = TRUE;
    }
    else if ((strcmp (argv[i], "NO-TACTICAL") == 0) ||
             (strcmp (argv[i], "TACTICAL-OFF") == 0))

```

```

    printf ("%s\n", argv[i]);
    TACTICAL = FALSE;
}
else if ((strcmp (argv[i], "SONARTRACE") == 0) ||
         (strcmp (argv[i], "SONAR-TRACE") == 0))
{
    if (TRACE && DISPLAYSCREEN) printf ("[SONARTRACE] ");
    SONARTRACE = TRUE;
}
else if ((strcmp (argv[i], "SONARTRACEOFF") == 0) ||
         (strcmp (argv[i], "SONAR-TRACE-OFF") == 0))
{
    if (TRACE && DISPLAYSCREEN) printf ("[SONARTRACEOFF] ");
    SONARTRACE = FALSE;
}
else if ((strcmp (argv[i], "SONARINSTALLED") == 0) ||
         (strcmp (argv[i], "SONAR-INSTALLED") == 0))
{
    if (TRACE && DISPLAYSCREEN) printf ("[SONARINSTALLED] ");
    SONARINSTALLED = TRUE;
}
else if ((strcmp (argv[i], "PARALLELPORTTRACE") == 0) ||
         (strcmp (argv[i], "PARALLEL-PORT-TRACE") == 0))
{
    if (TRACE && DISPLAYSCREEN) printf ("[PARALLELPORTTRACE] ");
    PARALLELPORTTRACE = TRUE;
}
else if ((strcmp (argv[i], "SILENT") == 0) ||
         (strcmp (argv[i], "SILENCE") == 0))
{
    if (TRACE && DISPLAYSCREEN) printf ("[SILENT] ");
    /* send to virtual world after socket is open */
    strcpy (buffer, "SILENT"); /* copy current command to buffer */
}
else if ((strcmp (argv[i], "TIMESTEP") == 0) ||
         (strcmp (argv[i], "TIME-STEP") == 0))
{
    i++;
    if (i >= argc) print_help = TRUE;
    else
    {
        sscanf (argv[i], "%F", &TIMESTEP);
        if (TRACE && DISPLAYSCREEN) printf ("[TIMESTEP %f]", TIMESTEP);
        if (TIMESTEP > 0.0) dt = TIMESTEP;
        else if (TRACE && DISPLAYSCREEN)
            printf("  illegal TIMESTEP value, ignored.");
        if (TRUE && DISPLAYSCREEN) printf(" [dt = %f]", dt);
    }
}
else if ((strcmp (argv[i], "REMOTEHOST") == 0) ||
         (strcmp (argv[i], "REMOTE-HOST") == 0) ||
         (strcmp (argv[i], "REMOTE") == 0) ||
         (strcmp (argv[i], "HOST") == 0))
{
    i++;
    if (i >= argc) print_help = TRUE;
    else
    {
        sscanf (argv[i], "%s", virtual_world_remote_host_name);
        if (TRACE && DISPLAYSCREEN)
            printf ("[REMOTE-HOST %s]", virtual_world_remote_host_name);
    }
}
else if ((strcmp (argv[i], "REALTIME") == 0) ||
         (strcmp (argv[i], "REAL-TIME") == 0))
{

```

```

        if (TRACE && DISPLAYSCREEN) printf ("[REALTIME] ");
        REALTIME = TRUE;
    }
    else if ((strcmp (argv[i], "NOREALTIME") == 0) ||
             (strcmp (argv[i], "NO-REALTIME") == 0) ||
             (strcmp (argv[i], "NO-REAL-TIME") == 0) ||
             (strcmp (argv[i], "NOWAIT") == 0) ||
             (strcmp (argv[i], "NO-WAIT") == 0) ||
             (strcmp (argv[i], "NOPAUSE") == 0) ||
             (strcmp (argv[i], "NO-PAUSE") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[NOWAIT] ");
        REALTIME = FALSE;
    }
    else if ((strcmp (argv[i], "NOEMAIL") == 0) ||
             (strcmp (argv[i], "NO-EMAIL") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[NO EMAIL] ");
        EMAIL = FALSE;
    }
    else print_help = TRUE; /* invalid command line entry parameter found */
} /* end for loop through command line parameters */

if (print_help) /* print help string *****/
{
    printf("\nUsage:  execution \n");
    print_valid_keywords ();
    exit (-1);
}

if (TRACE && DISPLAYSCREEN) printf ("\n[parse_command_line_flags complete]\n");
return;
} /* end parse_command_line_flags () */

/*****
void parse_mission_script_commands () /* get data from file at program start */
/* mission.script.HELP => descriptions */
{
    int    index, read_another_line, parameters_read;
    Souble parameter1, parameter2, parameter3, parameter4, parameter5;
    char   backupcommand [50], new_filename [30];

    if (TRACE && DISPLAYSCREEN)
        printf ("[start parse_mission_script_commands ()]\n");

    if ((auvscriptfile == NULL) || feof (auvscriptfile) || auvscriptfilequit)
    {
        if (DISPLAYSCREEN)
        {
            printf ("[opening a copy of the auvscriptfile %s]\n",
                    AUVSCRIPTFILENAME);
            fflush (stdout);
        }
    }
    #if defined(sgi)
        sprintf (backupcommand, "rm      mission.script.backup");
        printf ("%s\n", backupcommand);
        system (backupcommand);
        sprintf (backupcommand, "cp    %s mission.script.backup",
                AUVSCRIPTFILENAME);
        printf ("%s\n", backupcommand);
        system (backupcommand);
    #else
        /* OS-9 */

```

```

sprintf (backupcommand, "del      mission.script.backup");
printf ("%s\n", backupcommand);
system (backupcommand);
sprintf (backupcommand, "copy %s mission.script.backup",
        AUVSCRIPTFILENAME);
printf ("%s\n", backupcommand);
system (backupcommand);
#endif

auvscriptfile = fopen ("mission.script.backup","r"); /* input file */
if (auvscriptfile == NULL)
{
    printf ("AUV execution:  script file %s\n", AUVSCRIPTFILENAME);
    printf
    ("      (or backup copy mission.script.backup) not found.\n");
    printf ("      Ensure you are in the right directory:\n");
    printf ("      auvsim1> chd /h0/execution      or\n");
    printf ("      unix>   cd ~brutzman/execution\n");
    printf ("Exit.\n");
    exit (-1);
}
auvscriptfilequit = FALSE;

sprintf (buffer, "%s.backup", AUVORDERSFILENAME);
auvordersfile = fopen (buffer,"w"); /* output file */
if (TRACE && DISPLAYSCREEN)
    printf ("auvordersfile (%s) = %x\n", AUVORDERSFILENAME,
            auvordersfile);
if (auvordersfile == NULL)
{
    printf ("AUV execution:  %s file not opened.\n", buffer);
    printf ("      Error.\n");
    printf ("Exit.\n");
    exit (-1);
}
if (TRACE && DISPLAYSCREEN)
    printf ("[auvordersfile = %x, opened succesfully]\n",
            auvordersfile);

fprintf (auvordersfile,
"\n\n");
fprintf (auvordersfile,
"# NPS AUV file %s: commanded propulsion orders versus time\n",
        AUVORDERSFILENAME);
fprintf (auvordersfile,
"\n\n");
fprintf (auvordersfile,
"#
timestep:  %4.2f seconds\n", dt);
fprintf (auvordersfile,
"\n\n");
fprintf (auvordersfile,
"# time heading North East Depth      rpm      rpm      stern stern      vertical
lateral \n");
fprintf (auvordersfile,
"#          x      y      z      port stbd  plane  rudder  thrusters
thrusters\n");
fprintf (auvordersfile,
"#
bow/stern\n");
fprintf (auvordersfile,
"\n\n");
}
else if (TRACE && DISPLAYSCREEN)
    printf ("[auvscriptfile checks out as ready...]\n");

read_another_line = TRUE;

```

```

while (read_another_line == TRUE) /* ***** Parse loop ***** */
{
    parameter1 = 0.0;
    parameter2 = 0.0;
    parameter3 = 0.0;

    if (KEYBOARDINPUT == TRUE)
    {
        strcpy (buffer, "Enter mission script command");
        send_data_on_virtual_world_socket (); /* buffer msg sent */
        printf ("\n%s *** HERE ***: ", buffer);
        gets (command_buffer);
    }
    else
    {
        strcpy (command_buffer, "");
        fgets (command_buffer, 120, auvscriptfile);

        if (feof (auvscriptfile))
        {
            if (DISPLAYSCREEN)
            printf ("EOF condition: (%s copy) mission.script.backup, file closed)\n",
                    AUVSCRIPTFILENAME);
            fclose (auvscriptfile);
            auvscriptfilequit = TRUE;
            read_another_line = FALSE;
            end_test = TRUE;
            strcpy (command_buffer, "");
            break;
        }
    }

    if ((int)(strlen (command_buffer) <= 120) && TRACE && DISPLAYSCREEN)
    {
        printf ("strlen (command_buffer) = %d", strlen (command_buffer));
        printf (">>>%s<<<", command_buffer);
    }

    parameters_read = sscanf (command_buffer, "%s", keyword);

    if (TRACE && DISPLAYSCREEN)
    {
        printf ("parameters_read = %d, keyword = %s",
                parameters_read, keyword);
    }

    for (index=0; index<=(int)strlen (keyword); index++) /* set uppercase */
        keyword [index] = toupper (keyword [index]);

    audible_command = TRUE;

    if (TRACE && DISPLAYSCREEN)
    {
        printf ("uppercase keyword = %s\n", keyword);
    }

    if ((parameters_read != 1) ||
        (strlen (keyword) == 0) ||
        (strlen (command_buffer) == 0) ||
        (command_buffer [0] == '\n')) /* blank line */
    {
        audible_command = FALSE;
        printf ("\n");
    }
    else if (keyword [0] == '#') /* comment */
    {
        if (DISPLAYSCREEN) printf ("%s", command_buffer);
    }
}

```

```

        command_buffer [0] = ' ';
    }
    else if (((keyword [0] == '/') && (keyword [1] == '/')) ||
             ((keyword [0] == '*') && (keyword [1] == '*'))) /* comment */
    {
        if (DISPLAYSCREEN) printf ("%s", command_buffer);
        command_buffer [0] = ' ';
        command_buffer [1] = ' ';
    }
    else if ((strcmp (keyword, "HELP") == 0) ||
             (strcmp (keyword, "?") == 0) ||
             (strcmp (keyword, "-?") == 0) ||
             (strcmp (keyword, "/*") == 0))
    {
        if (DISPLAYSCREEN) printf ("[HELP] ");
        print_valid_keywords ();
    }
    else if ((strcmp (keyword, "WAIT") == 0) ||
             (strcmp (keyword, "RUN") == 0))
    {
        parameters_read = sscanf (command_buffer, "%s%lf",
                                   keyword, & parameter1);
        printf ("[%s %6.2f; ", keyword, parameter1);
        if ((parameters_read == 2) && (parameter1 >= 0.0))
        {
            read_another_line = FALSE;
            time_next_command = t + parameter1;
            printf ("time of next command %6.2f]\n",
                    time_next_command);
            fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
                    t, psi_command, x_command, y_command, z_command,
                    port_rpm_command, stbd_rpm_command,
                    rudder_command, planes_command,
                    bow_lateral_thruster_command,
                    stern_lateral_thruster_command,
                    bow_vertical_thruster_command,
                    stern_vertical_thruster_command);
        }
        else printf (" warning: illegal time value, ignored\n");
    }
    else if ((strcmp (keyword, "TIME") == 0) ||
             (strcmp (keyword, "WAITUNTIL") == 0) ||
             (strcmp (keyword, "PAUSEUNTIL") == 0))
    {
        parameters_read = sscanf (command_buffer, "%s%lf",
                                   keyword, & parameter1);
        printf ("[%s %6.2f]\n", keyword, parameter1);
        if (parameters_read == 2)
        {
            read_another_line = FALSE;
            time_next_command = parameter1;
            fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
                    t, psi_command, x_command, y_command, z_command,
                    port_rpm_command, stbd_rpm_command,
                    rudder_command, planes_command,
                    bow_lateral_thruster_command,
                    stern_lateral_thruster_command,
                    bow_vertical_thruster_command,
                    stern_vertical_thruster_command);
            if (parameter1 <= t)
            {
                t = parameter1;
                printf (" warning: time value has reset AUV clock.\n");
            }
        }
    }

```

```

        read_another_line = TRUE; /* no PDU */
    }
    }
    else printf (" warning: illegal time value, ignored.\n");
}
else if ((strcmp (keyword, "TIMESTEP") == 0) ||
        (strcmp (keyword, "TIME-STEP") == 0))
{
    if (sscanf (command_buffer, "%s%f", keyword, &parameter1) == 2)
    {
        if ((parameter1 > 0.0) && (parameter1 <= 5.0))
        {
            dt = parameter1;
            if (DISPLAYSCREEN)
                printf ("[TIMESTEP   %6.2f] ", dt);
            fprintf (auvordersfile, "# timestep:  %4.2f seconds\n", dt);
        }
        else print_help = TRUE;
    }
    else print_help = TRUE;
}
else if ((strcmp (keyword, "PAUSE") == 0) ||
        (strcmp (keyword, "-PAUSE") == 0))
{
    if (DISPLAYSCREEN)
    {
        printf ("[PAUSE]\n");
        strcpy (buffer, " Press any key to continue");
        send_data_on_virtual_world_socket (); /* buffer msg sent */
        printf ("\n%s *** HERE ***: ", buffer);
        answer = getchar (); /* pause */
    }
}
else if ((strcmp (keyword, "REALTIME") == 0) ||
        (strcmp (keyword, "REAL-TIME") == 0))
{
    if (DISPLAYSCREEN) printf ("[REALTIME] ");
    REALTIME = TRUE;
}
else if ((strcmp (keyword, "MISSION") == 0) ||
        (strcmp (keyword, "SCRIPT") == 0) ||
        (strcmp (keyword, "FILENAME") == 0))
{
    parameters_read = sscanf (command_buffer, "%s%s",
                                keyword, new_filename);
    if (parameters_read == 2)
    {
        if (DISPLAYSCREEN)
            printf ("[%s   %s]\n", keyword, new_filename);
#ifdef (sgi)
        sprintf (backupcommand, "cp   %s %s", new_filename,
                    AUVSCRIPTFILENAME);
#else
        sprintf (backupcommand, "copy %s %s", new_filename,
                    AUVSCRIPTFILENAME);
#endif
        if (DISPLAYSCREEN)
            printf ("%s\n", backupcommand);
        system ( backupcommand);
    }
    else
    {
        if (DISPLAYSCREEN)
            printf ("[%s] warning: no filename present, ignored\n", keyword);
    }
}
else if ((strcmp (keyword, "KEYBOARD") == 0) ||

```

```

        (strcmp (keyword, "KEYBOARD-ON") == 0) ||
        (strcmp (keyword, "KEYBOARD-INPUT") == 0) ||
        (strcmp (keyword, "KEYBOARDINPUT") == 0))
    {
        if (DISPLAYSCREEN) printf ("[%s]\n", keyword);
        KEYBOARDINPUT = TRUE;
    }
    else if ((strcmp (keyword, "KEYBOARD-OFF") == 0) ||
             (strcmp (keyword, "NO-KEYBOARD") == 0))
    {
        if (DISPLAYSCREEN) printf ("[%s]\n", keyword);
        KEYBOARDINPUT = FALSE;
    }
    else if ((strcmp (keyword, "NOWAIT") == 0) ||
             (strcmp (keyword, "NO-WAIT") == 0) ||
             (strcmp (keyword, "NOREALTIME") == 0) ||
             (strcmp (keyword, "NO-REALTIME") == 0) ||
             (strcmp (keyword, "NONREALTIME") == 0) ||
             (strcmp (keyword, "NO-PAUSE") == 0) ||
             (strcmp (keyword, "NOPAUSE") == 0))
    {
        if (DISPLAYSCREEN) printf ("[%s]\n", keyword);
        REALTIME = FALSE;
    }
    else if ((strcmp (keyword, "QUIT") == 0) ||
             (strcmp (keyword, "STOP") == 0) ||
             (strcmp (keyword, "DONE") == 0) ||
             (strcmp (keyword, "EXIT") == 0) ||
             (strcmp (keyword, "REPEAT") == 0) ||
             (strcmp (keyword, "RESTART") == 0) ||
             (strcmp (keyword, "COMPLETE") == 0) ||

             (strcmp (keyword, "KILL") == 0) ||
             (strcmp (keyword, "SHUTDOWN") == 0))
    {
        /* note this command does not reset LOOPFOREVER, except for */
        /* KILL/SHUTDOWN which terminate the dynamics model connection */
        if ((strcmp (keyword, "KILL") == 0) ||
            (strcmp (keyword, "SHUTDOWN") == 0))
        {
            LOOPFOREVER = FALSE;
            strcpy (buffer, "KILL");
            send_data_on_virtual_world_socket (); /* buffer msg sent */
        }
        printf ("[%s]\n", keyword);
        if (DISPLAYSCREEN) printf ("[end_test set TRUE]\n");
        end_test = TRUE;
        read_another_line = FALSE;

        fclose (auvscriptfile);
        auvscriptfilequit = TRUE;
        if (DISPLAYSCREEN)
            printf ("[QUIT condition: (%s backup file) mission.script.backup, file closed]\n",
                    AUVSCRIPTFILENAME);
        fprintf (auvordersfile,
            "%6.1f %6.1f %5.1f %5.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
            t, psi_command, x_command, y_command, z_command,
            port_rpm_command, stbd_rpm_command,
            rudder_command, planes_command,
            bow_lateral_thruster_command,
            stern_lateral_thruster_command,
            bow_vertical_thruster_command,
            stern_vertical_thruster_command);
        x_dot = 0.0;
        y_dot = 0.0;
        z_dot = 0.0;
    }

```

```

phi_dot          = 0.0; /* degrees/sec */
theta_dot        = 0.0; /* degrees/sec */
psi_dot          = 0.0; /* degrees/sec */
speed            = 0.0;
u                = 0.0;
v                = 0.0;
w                = 0.0;
p                = 0.0; /* degrees/sec */
q                = 0.0; /* degrees/sec */
r                = 0.0; /* degrees/sec */
delta_planes     = 0.0; /* degrees */
delta_rudder     = 0.0; /* degrees */
port_rpm         = 0;
stbd_rpm         = 0;
vertical_thruster_volts = 0.0;
lateral_thruster_volts = 0.0;

else if ((strcmp (keyword, "RPM") == 0) ||
         (strcmp (keyword, "SPEED") == 0) ||
         (strcmp (keyword, "PROPS") == 0) ||
         (strcmp (keyword, "PROPELLORS") == 0))

parameters_read = sscanf (command_buffer, "%s%lf%lf",
                           keyword, & parameter1,
                           & parameter2);

if (parameters_read == 3)
{
    printf ("[%s %6.2f %6.2f]\n", keyword, parameter1,
                                         parameter2);
    port_rpm_command = parameter1;
    stbd_rpm_command = parameter2;
}
else
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                              keyword, & parameter1);
    printf ("[%s %6.2f]\n", keyword, parameter1);
    if (parameters_read == 2)
    {
        port_rpm_command = parameter1;
        stbd_rpm_command = parameter1;
    }
    else printf (" warning: no value, ignored\n");
}
}
else if ((strcmp (keyword, "COURSE") == 0) ||
         (strcmp (keyword, "HEADING") == 0) ||
         (strcmp (keyword, "YAW") == 0))

parameters_read = sscanf (command_buffer, "%s%lf",
                           keyword, & parameter1);
printf ("[%s %6.2f]\n", keyword, parameter1);
if (parameters_read == 2)
{
    DEADSTICKRUDDER = FALSE;
    WAYPOINTCONTROL = FALSE;
    psi_command      = parameter1;
    rotate_command   = 0.0;
    lateral_command   = 0.0;
    ROTATECONTROL    = FALSE;
    LATERALCONTROL    = FALSE;
}
else printf (" warning: no value, ignored\n");
}
else if ((strcmp (keyword, "TURN") == 0) ||
         (strcmp (keyword, "CHANGE-COURSE") == 0))

```

```

{
    parameters_read = sscanf (command_buffer, "%s%lf",
                                keyword, & parameter1);
    printf ("[%s %6.2f]\n", keyword, parameter1);
    if (parameters_read == 2)
    {
        DEADSTICKRUDDER = FALSE;
        WAYPOINTCONTROL = FALSE;
        ROTATECONTROL = FALSE;
        psi_command = psi_command + parameter1;
    }
    else printf (" warning: no value, ignored\n");
}
else if (strcmp (keyword, "RUDDER") == 0)
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                                keyword, & parameter1);
    printf ("[%s %6.2f]\n", keyword, parameter1);
    if (parameters_read == 2)
    {
        DEADSTICKRUDDER = TRUE;
        WAYPOINTCONTROL = FALSE;
        ROTATECONTROL = FALSE;
        HOVERCONTROL = FALSE;
        rudder_command = parameter1;
    }
    else
    {
        printf (" warning: improper value, rudder order ignored\n");
    }
}
else if (strcmp (keyword, "DEADSTICKRUDDER") == 0)
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                                keyword, & parameter1);
    if (parameters_read == 2)
    {
        printf ("[%s %6.2f]\n", keyword, parameter1);
        DEADSTICKRUDDER = TRUE;
        WAYPOINTCONTROL = FALSE;
        ROTATECONTROL = FALSE;
        HOVERCONTROL = FALSE;
        rudder_command = parameter1;
    }
    else
    {
        printf ("[%s] ", keyword);
        DEADSTICKRUDDER = TRUE;
        WAYPOINTCONTROL = FALSE;
        ROTATECONTROL = FALSE;
        rudder_command = 0.0;
        printf (" warning: improper value, rudder set to 0\n");
    }
}
else if (strcmp (keyword, "DEPTH") == 0)
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                                keyword, & parameter1);
    printf ("[%s %6.2f]\n", keyword, parameter1);
    if (parameters_read == 2)
    {
        DEADSTICKPLANES = FALSE;
        z_command = parameter1;
    }
    else printf (" warning: no value, ignored\n");
}
else if (strcmp (keyword, "PLANES") == 0)

```

```

parameters_read = sscanf (command_buffer, "%s%lf",
                           keyword, & parameter1);
printf ("[%s %6.2f]\n", keyword, parameter1);
if (parameters_read == 2)
{
    DEADSTICKPLANES = TRUE;
    planes_command = parameter1;
}
else printf (" warning: improper value, planes order ignored\n");
}
else if (strcmp (keyword, "DEADSTICKPLANES") == 0)
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                              keyword, & parameter1);
    if (parameters_read == 2)
    {
        printf ("[%s %6.2f]\n", keyword, parameter1);
        DEADSTICKPLANES = TRUE;
        planes_command = parameter1;
    }
    else
    {
        printf ("[%s] ", keyword);
        DEADSTICKPLANES = TRUE;
        planes_command = 0.0;
        printf (" warning: improper value, planes set to 0\n");
    }
}
else if ((strcmp (keyword, "THRUSTERS-ON") == 0) ||
         (strcmp (keyword, "THRUSTERS") == 0) ||
         (strcmp (keyword, "THRUSTERON") == 0) ||
         (strcmp (keyword, "THRUSTERSON") == 0))
{
    printf ("[%s]\n", keyword);
    THRUSTERCONTROL = TRUE;
}
else if ((strcmp (keyword, "NOTHRUSTER") == 0) ||
         (strcmp (keyword, "NOTHRUSTERS") == 0) ||
         (strcmp (keyword, "THRUSTERS-OFF") == 0) ||
         (strcmp (keyword, "THRUSTERSOFF") == 0))
{
    printf ("[%s]\n", keyword);
    THRUSTERCONTROL = FALSE;
}
else if (strcmp (keyword, "ROTATE") == 0)
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                              keyword, & parameter1);
    printf ("[%s %6.2f]\n", keyword, parameter1);
    if (parameters_read == 2)
    {
        THRUSTERCONTROL = TRUE;
        WAYPOINTCONTROL = FALSE;
        HOVERCONTROL = FALSE;
        rotate_command = parameter1;
        clamp (&rotate_command, -12.0, 12.0, "rotate_command");
        lateral_command = 0.0;
        ROTATECONTROL = TRUE;
        LATERALCONTROL = FALSE;
    }
    else printf (" warning: no value, ignored\n");
}
else if ((strcmp (keyword, "NOROTATE") == 0) ||
         (strcmp (keyword, "ROTATEOFF") == 0) ||
         (strcmp (keyword, "ROTATE-OFF") == 0))
{

```

```

printf ("[%s]\n", keyword);
rotate_command = 0.0;
ROTATECONTROL = FALSE;
}
else if (strcmp (keyword, "LATERAL") == 0)
{
parameters_read = sscanf (command_buffer, "%s%lf",
                           keyword, & parameter1);
printf ("[%s %6.2f]\n", keyword, parameter1);
if (parameters_read == 2)
{
THRUSTERCONTROL = TRUE;
WAYPOINTCONTROL = FALSE;
HOVERCONTROL = FALSE;
rotate_command = 0.0;
lateral_command = parameter1;
clamp (& lateral_command, -0.5, 0.5, "lateral_command");
ROTATECONTROL = FALSE;
LATERALCONTROL = TRUE;
}
else printf (" warning: no value, ignored\n");
}
else if ((strcmp (keyword, "NOLATERAL") == 0) ||
         (strcmp (keyword, "LATERALOFF") == 0) ||
         (strcmp (keyword, "LATERAL-OFF") == 0))
{
printf ("[%s]\n", keyword);
lateral_command = 0.0;
LATERALCONTROL = FALSE;
}
else if ((strcmp (keyword, "POSITION") == 0) ||
         (strcmp (keyword, "LOCATION") == 0) )
{
parameters_read = sscanf (command_buffer, "%s%lf%lf%lf",
                           keyword, & parameter1,
                           & parameter2, & parameter3);
printf ("[%s %6.2f %6.2f %6.2f]\n", keyword, parameter1,
                                           parameter2, parameter3);
if (parameters_read == 4)
{
x = parameter1;
y = parameter2;
z = parameter3;
/* skip line in telemetry file to break point-to-point lines */
fprintf (auvdatafile, "\n");
}
else printf (" warning: invalid x/y/z position, ignored\n");
}
else if ((strcmp (keyword, "ORIENTATION") == 0) ||
         (strcmp (keyword, "ROTATION") == 0) )
{
parameters_read = sscanf (command_buffer, "%s%lf%lf%lf",
                           keyword, & parameter1,
                           & parameter2, & parameter3);
printf ("[%s %6.2f %6.2f %6.2f]\n", keyword, parameter1,
                                           parameter2, parameter3);
if (parameters_read == 4)
{
phi = parameter1;
theta = parameter2;
psi = parameter3;
}
else
printf (" warning: invalid phi/theta/psi orientation, ignored\n");
}
else if ((strcmp (keyword, "CONTINUE") == 0) ||
         (strcmp (keyword, "GO") == 0))

```

```

    {
        if (DISPLAYSCREEN) printf ("[%s]", keyword);
        return; /* no action required */
    }
    else if ((strcmp (keyword, "STEP") == 0) ||
              (strcmp (keyword, "SINGLE-STEP") == 0))
    {
        if (DISPLAYSCREEN) printf ("[%s]", keyword);
        time_next_command = t + dt;
        read_another_line = FALSE;
    }
    else if ((strcmp (keyword, "TRACE") == 0) ||
              (strcmp (keyword, "TRACE-ON") == 0))
    {
        if (DISPLAYSCREEN) printf ("[TRACE = TRUE] ");
        TRACE = TRUE;
    }
    else if ((strcmp (keyword, "TRACEOFF") == 0) ||
              (strcmp (keyword, "TRACE-OFF") == 0) ||
              (strcmp (keyword, "NOTRACE") == 0) ||
              (strcmp (keyword, "NO-TRACE") == 0))
    {
        if (DISPLAYSCREEN) printf ("[TRACE = FALSE] ");
        TRACE = FALSE;
    }
    else if ((strcmp (keyword, "LOOPFOREVER") == 0) ||
              (strcmp (keyword, "LOOP-FOREVER") == 0))
    {
        if (DISPLAYSCREEN) printf ("[LOOPFOREVER] ");
        LOOPFOREVER = TRUE;
    }
    else if ((strcmp (keyword, "LOOPONCE") == 0) ||
              (strcmp (keyword, "LOOP-ONCE") == 0))
    {
        if (DISPLAYSCREEN) printf ("[LOOPONCE] ");
        LOOPFOREVER = FALSE;
    }
    else if ((strcmp (keyword, "LOOPFILEBACKUP") == 0) ||
              (strcmp (keyword, "LOOP-FILE-BACKUP") == 0))
    {
        if (DISPLAYSCREEN) printf ("[LOOPFILEBACKUP] ");
        LOOPFILEBACKUP = TRUE;
    }
    else if ((strcmp (keyword, "ENTERCONTROLCONSTANTS") == 0) ||
              (strcmp (keyword, "ENTER-CONTROL-CONSTANTS") == 0))
    {
        if (DISPLAYSCREEN) printf ("[ENTERCONTROLCONSTANTS] ");
        ENTERCONTROLCONSTANTS = TRUE;
        get_control_constants ();
        fflush (stdin);
    }
    else if ((strcmp (keyword, "SLIDINGMODECOURSE") == 0) ||
              (strcmp (keyword, "SLIDING-MODE-COURSE") == 0))
    {
        printf ("[%s = TRUE]\n", keyword);
        SLIDINGMODECOURSE = TRUE;
        WAYPOINTCONTROL = FALSE;
        ROTATECONTROL = FALSE;
        HOVERCONTROL = FALSE;
    }
    else if ((strcmp (keyword, "SLIDINGMODEOFF") == 0) ||
              (strcmp (keyword, "SLIDING-MODE-OFF") == 0))
    {
        printf ("[%s: SLIDINGMODECOURSE = FALSE]\n", keyword);
        SLIDINGMODECOURSE = FALSE;
    }
    else if ((strcmp (keyword, "TACTICAL") == 0) ||

```

```

        (strcmp (keyword, "TACTICAL-ON") == 0))
    {
        printf ("%s\n", keyword);
        TACTICAL = TRUE;
    }
    else if ((strcmp (keyword, "NO-TACTICAL") == 0) ||
             (strcmp (keyword, "TACTICAL-OFF") == 0))
    {
        printf ("%s\n", keyword);
        TACTICAL = FALSE;
    }
    else if (strcmp (keyword, "SONARTRACE") == 0)
    {
        if (DISPLAYSCREEN) printf ("[SONARTRACE] ");
        SONARTRACE = TRUE;
    }
    else if (strcmp (keyword, "SONARTRACEOFF") == 0)
    {
        if (DISPLAYSCREEN) printf ("[SONARTRACEOFF] ");
        SONARTRACE = FALSE;
    }
    else if (strcmp (keyword, "SONARINSTALLED") == 0)
    {
        if (DISPLAYSCREEN) printf ("[SONARINSTALLED] ");
        SONARINSTALLED = TRUE;
    }
    else if (strcmp (keyword, "PARALLELPORTRACE") == 0)
    {
        if (DISPLAYSCREEN) printf ("[PARALLELPORTRACE] ");
        PARALLELPORTRACE = TRUE;
    }
    else if ((strcmp (keyword, "AUDIBLE") == 0) ||
             (strcmp (keyword, "AUDIO") == 0) ||
             (strcmp (keyword, "AUDIO-ON") == 0) ||
             (strcmp (keyword, "SOUND-ON") == 0) ||
             (strcmp (keyword, "SOUNDON") == 0) ||
             (strcmp (keyword, "SOUND") == 0))
    {
        if (DISPLAYSCREEN) printf ("[AUDIBLE] ");
        strcpy (buffer, "AUDIBLE"); /* copy current command to buffer */
        send_data_on_virtual_world_socket (); /* send to sound driver */
    }
    else if ((strcmp (keyword, "SILENT") == 0) ||
             (strcmp (keyword, "SILENCE") == 0) ||
             (strcmp (keyword, "NOSOUND") == 0) ||
             (strcmp (keyword, "SOUNDOFF") == 0) ||
             (strcmp (keyword, "SOUND-OFF") == 0) ||
             (strcmp (keyword, "AUDIOOFF") == 0) ||
             (strcmp (keyword, "AUDIO-OFF") == 0) ||
             (strcmp (keyword, "QUIET") == 0))
    {
        if (DISPLAYSCREEN) printf ("[SILENT] ");
        strcpy (buffer, "SILENT"); /* copy current command to buffer */
        send_data_on_virtual_world_socket (); /* send to sound driver */
    }
    else if ((strcmp (keyword, "EMAIL") == 0) ||
             (strcmp (keyword, "EMAIL-ON") == 0) ||
             (strcmp (keyword, "E-MAIL") == 0) ||
             (strcmp (keyword, "E-MAIL-ON") == 0) ||
             (strcmp (keyword, "EMAILON") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[EMAIL ON] ");
        EMAIL = TRUE;
    }
    else if ((strcmp (keyword, "EMAILOFF") == 0) ||
             (strcmp (keyword, "EMAIL-OFF") == 0) ||
             (strcmp (keyword, "E-MAILOFF") == 0) ||

```

```

        (strcmp (keyword, "E-MAIL-OFF") == 0) ||
        (strcmp (keyword, "NO-E-MAIL") == 0) ||
        (strcmp (keyword, "NO-EMAIL") == 0) ||
        (strcmp (keyword, "NO-E-MAIL") == 0) ||
        (strcmp (keyword, "NOEMAIL") == 0))
    {
        if (TRACE && DISPLAYSCREEN) printf ("[EMAIL OFF] ");
        EMAIL = FALSE;
    }
    else if ((strcmp (keyword, "WAYPOINT") == 0) ||
             (strcmp (keyword, "WAYPOINT-ON") == 0))
    {
        parameters_read = sscanf (command_buffer, "%s%lf%lf%lf",
                                   keyword, & parameter1,
                                   & parameter2, & parameter3);

        if (parameters_read == 4)
        {
            printf ("[%s %6.2f %6.2f %6.2f]\n", keyword, parameter1,
                                                            parameter2, parameter3);
            WAYPOINTCONTROL = TRUE;
            x_command = parameter1;
            y_command = parameter2;
            z_command = parameter3;
            port_rpm_command = fabs (port_rpm_command); /* ensure fwd */
            stbd_rpm_command = fabs (stbd_rpm_command); /* motion only */
            fprintf (auvordersfile,
                    "%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
                    t, psi_command, x_command, y_command, z_command,
                    port_rpm_command, stbd_rpm_command,
                    rudder_command, planes_command,
                    bow_lateral_thruster_command,
                    stern_lateral_thruster_command,
                    bow_vertical_thruster_command,
                    stern_vertical_thruster_command);
        }
        else if (parameters_read == 3)
        {
            printf ("[%s %6.2f %6.2f]\n", keyword, parameter1,
                                                            parameter2);
            WAYPOINTCONTROL = TRUE;
            x_command = parameter1;
            y_command = parameter2;
            port_rpm_command = fabs (port_rpm_command); /* ensure fwd */
            stbd_rpm_command = fabs (stbd_rpm_command); /* motion only */
            fprintf (auvordersfile,
                    "%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
                    t, psi_command, x_command, y_command, z_command,
                    port_rpm_command, stbd_rpm_command,
                    rudder_command, planes_command,
                    bow_lateral_thruster_command,
                    stern_lateral_thruster_command,
                    bow_vertical_thruster_command,
                    stern_vertical_thruster_command);
        }
        else
        {
            WAYPOINTCONTROL = FALSE;
            printf ("\n warning: improper number of values\n waypoint");
            printf ("set to current position but otherwise ignored\n");
            x_command = x;
            y_command = y;
            z_command = z;
            fprintf (auvordersfile,
                    "%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
                    t, psi_command, x_command, y_command, z_command,
                    port_rpm_command, stbd_rpm_command,
                    rudder_command, planes_command,
                    bow_lateral_thruster_command,
                    stern_lateral_thruster_command,
                    bow_vertical_thruster_command,
                    stern_vertical_thruster_command);
        }
    }
}

```

```

        t, psi_command, x_command, y_command, z_command,
        port_rpm_command, stbd_rpm_command,
        rudder_command, planes_command,
        bow_lateral_thruster_command,
        stern_lateral_thruster_command,
        bow_vertical_thruster_command,
        stern_vertical_thruster_command);
    }
    if (FOLLOWWAYPOINTMODE == TRUE)
    {
        if (TRACE) printf ("[FOLLOWWAYPOINTMODE check]");
        /* continue until WAYPOINT reached without further script orders */
        time_next_command = t + 2.0 * dt;
        read_another_line = FALSE;
    }
}
else if ((strcmp (keyword, "WAYPOINTFOLLOW") == 0) ||
         (strcmp (keyword, "WAYPOINT-FOLLOW") == 0) )
{
    printf ("[%s]\n", keyword);
    FOLLOWWAYPOINTMODE = TRUE;
}
else if ((strcmp (keyword, "WAYPOINTFOLLOWOFF") == 0) ||
         (strcmp (keyword, "WAYPOINT-FOLLOW-OFF") == 0) )
{
    printf ("[%s]\n", keyword);
    FOLLOWWAYPOINTMODE = FALSE;
}
else if ((strcmp (keyword, "STANDOFF") == 0) ||
         (strcmp (keyword, "STAND-OFF") == 0) ||
         (strcmp (keyword, "STANDOFFDISTANCE") == 0) ||
         (strcmp (keyword, "STANDOFF-DISTANCE") == 0) ||
         (strcmp (keyword, "STAND-OFF-DISTANCE") == 0))
{
    parameters_read = sscanf (command_buffer, "%s%lf",
                               keyword, & parameter1);
    if (parameters_read == 2)
    {
        printf ("[%s %6.2f]\n", keyword, parameter1);
        standoff_distance = parameter1;
    }
    else
    {
        printf ("[%s]\n", keyword);
        printf (" warning: no standoff value provided, ignored");
    }
}
else if ((strcmp (keyword, "HOVER") == 0) ||
         (strcmp (keyword, "HOVER-ON") == 0))
{
    parameters_read = sscanf (command_buffer, "%s%lf%lf%lf%lf%lf",
                               keyword, & parameter1,
                               & parameter2, & parameter3,
                               & parameter4, & parameter5);
    if (parameters_read == 6)
    {
        printf ("[%s %6.2f %6.2f %6.2f %6.2f %6.2f]\n",
                keyword, parameter1,
                parameter2, parameter3,
                parameter4, parameter5);

        HOVERCONTROL = TRUE;
        WAYPOINTCONTROL = FALSE;
        ROTATECONTROL = FALSE;
        THRUSTERCONTROL = TRUE;
        DEADSTICKRUDDER = TRUE;
        FOLLOWWAYPOINTMODE = FALSE;
    }
}

```

```

        rudder_command      = 0.0;
        x_command           = parameter1;
        y_command           = parameter2;
        z_command           = parameter3;
        psi_command         = parameter4;
        psi_command_hover   = parameter4;
        standoff_distance   = parameter5;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f
%5.1f\n",
            t, psi_command, x_command, y_command, z_command,
            port_rpm_command, stbd_rpm_command,
            rudder_command, planes_command,
            bow_lateral_thruster_command,
            stern_lateral_thruster_command,
            bow_vertical_thruster_command,
            stern_vertical_thruster_command);
    }
    else if (parameters_read == 5)
    {
        printf ("%s %6.2f %6.2f %6.2f %6.2f]\n",
            keyword, parameter1,
            parameter2, parameter3,
            parameter4);

        HOVERCONTROL      = TRUE;
        WAYPOINTCONTROL    = FALSE;
        ROTATECONTROL      = FALSE;
        THRUSTERCONTROL    = TRUE;
        DEADSTICKRUDDER    = TRUE;
        FOLLOWWAYPOINTMODE = FALSE;
        rudder_command     = 0.0;
        x_command          = parameter1;
        y_command          = parameter2;
        z_command          = parameter3;
        psi_command        = parameter4;
        psi_command_hover  = parameter4;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f
%5.1f\n",
            t, psi_command, x_command, y_command, z_command,
            port_rpm_command, stbd_rpm_command,
            rudder_command, planes_command,
            bow_lateral_thruster_command,
            stern_lateral_thruster_command,
            bow_vertical_thruster_command,
            stern_vertical_thruster_command);
    }
    else if (parameters_read == 4)
    {
        printf ("%s %6.2f %6.2f %6.2f]\n", keyword, parameter1,
            parameter2, parameter3);

        HOVERCONTROL      = TRUE;
        WAYPOINTCONTROL    = FALSE;
        ROTATECONTROL      = FALSE;
        THRUSTERCONTROL    = TRUE;
        DEADSTICKRUDDER    = TRUE;
        FOLLOWWAYPOINTMODE = FALSE;
        rudder_command     = 0.0;
        x_command          = parameter1;
        y_command          = parameter2;
        z_command          = parameter3;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f
%5.1f\n",
            t, psi_command, x_command, y_command, z_command,
            port_rpm_command, stbd_rpm_command,
            rudder_command, planes_command,

```

```

        bow_lateral_thruster_command,
        stern_lateral_thruster_command,
        bow_vertical_thruster_command,
        stern_vertical_thruster_command);
    )
    else if (parameters_read == 3)
    {
        printf ("[%s   %6.2f %6.2f]\n", keyword, parameter1,
                                                    parameter2);
        HOVERCONTROL      = TRUE;
        WAYPOINTCONTROL    = FALSE;
        ROTATECONTROL      = FALSE;
        THRUSTERCONTROL    = TRUE;
        DEADSTICKRUDDER    = TRUE;
        FOLLOWWAYPOINTMODE = FALSE;
        rudder_command     = 0.0;
        x_command           = parameter1;
        y_command           = parameter2;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
t, psi_command, x_command, y_command, z_command,
port_rpm_command, stbd_rpm_command,
rudder_command, planes_command,
bow_lateral_thruster_command,
stern_lateral_thruster_command,
bow_vertical_thruster_command,
stern_vertical_thruster_command);
    }
    else if (parameters_read == 1)
    {
        printf ("[%s]\n", keyword);
        HOVERCONTROL      = TRUE;
        WAYPOINTCONTROL    = FALSE;
        ROTATECONTROL      = FALSE;
        THRUSTERCONTROL    = TRUE;
        DEADSTICKRUDDER    = TRUE;
        FOLLOWWAYPOINTMODE = FALSE;
        rudder_command     = 0.0;
        fprintf (auvordersfile,
"%6.1f %6.1f %5.1f %5.1f %5.1f %6.1f %6.1f %6.1f %6.1f %5.1f %5.1f %5.1f\n",
t, psi_command, x_command, y_command, z_command,
port_rpm_command, stbd_rpm_command,
rudder_command, planes_command,
bow_lateral_thruster_command,
stern_lateral_thruster_command,
bow_vertical_thruster_command,
stern_vertical_thruster_command);
    }
    else
    {
        printf ("[%s]\n", keyword);
        printf (" warning: improper number of values, ignored\n");
    }
}
else parse_mission_string_commands (command_buffer);
/* check other possibilities */

if (audible_command == TRUE)
{
    strcpy (buffer, command_buffer); /* copy current command to buffer */
    send_data_on_virtual_world_socket (); /* send to sound driver */
}

if ((print_help == TRUE) && DISPLAYSCREEN)
{

```

```

        printf ("%s", command_buffer);
        print_valid_keywords ();

        strcpy (buffer, " is an unknown command"); /* copy msg to buffer */
        send_data_on_virtual_world_socket ();      /* send to sound driver */
    }
    print_help = FALSE; /* reset value */

} /* loop until read_another_line is FALSE) */

if (TRACE && DISPLAYSCREEN)
    printf ("[end parse_mission_script_commands ()]\n");

return;

} /* end parse_mission_script_commands () */

/*****

void parse_mission_string_commands (command)
    char * command;

    int     index;
    int     number_values = 0;
    char     parameter2 [60];

    if (TRACE && DISPLAYSCREEN)
        printf ("\n[parse_mission_string_commands start]\n");

    number_values = sscanf (command_buffer, "%s", keyword);

    for (index = 0; index <= (int) strlen (keyword); index++)
        keyword [index] = toupper (keyword [index]);

    if      (number_values != 1)
    {
        if (DISPLAYSCREEN) printf (" [no parse word found]\n");
        return;
    }

    if ((strcmp (keyword, "REMOTEHOST") == 0) ||
        (strcmp (keyword, "REMOTE") == 0) ||
        (strcmp (keyword, "REMOTE-HOST") == 0) ||
        (strcmp (keyword, "HOST") == 0))
    {
        if (sscanf (command, "%s %s", keyword, parameter2) == 2)
        {
            strcpy (virtual_world_remote_host_name, parameter2);
            if (DISPLAYSCREEN) printf ("[REMOTE-HOST %s] ",
                                     virtual_world_remote_host_name);
        }
        else print_help = TRUE;
    }
    else print_help = TRUE; /* invalid command line entry parameter found */

    if (TRACE && DISPLAYSCREEN)
        printf ("\n[parse_mission_string_commands complete]\n");

    return;

}/* end parse_mission_string_commands () */

*****/

```

E. *globals.c* Global Variable Instantiation

```

/*****
/*
Program:      globals.c

Authors:      Don Brutzman

Revised:      21 October 94

System:       AUV Gespac 68020/68030, OS-9 version 2.4
Compiler:     Gespac cc Kernighan & Richie (K&R) C

Compilation:  ftp>      put globals.c
               auvsim1> chd execution
               [68020]   auvsim1> make -k2f execution
               [68030]   auvsim1> make      execution

               [Irix ]   fletch> make execution

Purpose:      Allows repeated use of global variables global.c via global.h
               in order to prevent compiler warnings
*/
*****/

#include "defines.h"

/*****
/* Program configuration flags
*****/

int  TRACE                = 0; /* 1=trace on,      0=trace off      */
int  DISPLAYSCREEN        = 1; /* 1=screen on,    0=screen off    */
int  LOCATIONLAB          = 1; /* 1=graphics lab, 0=actual vehicle */
int  TACTICAL             = 0; /* 1=tactical on,  0=tactical off   */
int  LOOPFOREVER          = 0; /* 1=repeat execution indefinitely */
int  LOOPFILEBACKUP       = 1; /* 1=backup files between replications */

int  PARALLELPORTTRACE    = 0; /* 1=trace each char received at port */
int  SONARINSTALLED       = 0; /* 1=sonar head available for query   */
int  SONARTRACE           = 0; /* 1=trace on,      0=trace off      */
int  ENTERCONTROLCONSTANTS = 0; /* 1>manual entry,  0=default values */
int  REALTIME             = 1; /* 1=1 second real-time waits, 0=none */

int  DEADRECKON           = 0; /* 1=dead reckon navigate, 0=regular */
int  DEADSTICKRUDDER      = 0; /* 1=use ordered rudder, 0 = control */
int  DEADSTICKPLANES      = 0; /* 1=use ordered planes, 0 = control */
int  SLIDINGMODECOURSE    = 0; /* 1=use sliding mode,   0 = control */

int  THRUSTERCONTROL      = 0; /* 1=use thrusters, 0=use propellers */
int  ROTATECONTROL        = 0; /* 1=use thrusters to rotate in place */
int  LATERALCONTROL       = 0; /* 1=use thrusters for lateral motion */
int  FOLLOWWAYPOINTMODE    = 0; /* 1= go to WAYPOINT without WAITs    */
int  WAYPOINTCONTROL      = 0; /* 1= go to WAYPOINT                  */
int  HOVERCONTROL         = 0; /* 1=hover at WAYPOINT                */

#if defined(sgi)
int  EMAIL                = 1; /* 1=send e-mail, 0=don't send e-mail */
#else
int  EMAIL                = 0; /* can't send e-mail via OS-9 directly */
#endif

int  NOT_YET_REIMPLEMENTED = 0; /* code in block needs reverification */

```

```

double TIMESTEP                = 0.1; /* time of a single closed loop      */
                                /* add code to warn if exceeded <<<< */

int    KEYBOARDINPUT           = 0;  /* 1=read keyboard vice mission file */

/* ===== */
/* files and paths */
FILE * auvscriptfile;
FILE * auvordersfile;
FILE * auvdatafile;
FILE * auvtextfile;
FILE * controlconstantsfile;
FILE * emailaddressfile;

/* FILE * serialtestfile; */

int    serialpath = 0;

int    sonarpath  = 0;

/* ===== */
/* Variables and data structures */

/* buffers of full strings for byte transfer to tactical level & disk file */
/* 'buffer' usually < 256, intentionally oversized in case of overflow error */

time_t      system_time      = 0;
struct tm   *system_tmp      = 0;

/* partial structure template for the MFI (only interested in PIA for now) */
struct MFI_PIA
{
    unsigned short pra;          /* port    register A - data direction A */
    unsigned short cra;          /* control register A */
    unsigned short prb;          /* port    register B - data direction B */
    unsigned short crb;          /* control register B */
};

/* 4 Channels of DAC ADA-1 DAC */
unsigned char *dac1_a = (unsigned char *) DAC1_ADDR;

/* 8 Channels of DAC DAC-2B */
unsigned char *dac2b_a = (unsigned char *) DAC2B_ADDR;

/* 16 Channels of ADC ADA-1 */
unsigned char *adc1_a = (unsigned char *) ADC1_ADDR;

/* 16 Channels of ADC ADC-2 */
unsigned short *adc2_a = (unsigned short *) ADC2_ADDR;

unsigned short *via0 = (unsigned short *) VIA0_ADDR;

int    telemetry_records_saved = 0;
int    mission_leg_counter     = 0;
int    replication_count       = 1;
int    end_test                 = FALSE;
int    wrap_count               = 0;
double t                        = 0.0;
double dt                       = 0.1;
double rpm                      = 0.0;
double speed_limit              = 0.0;
double main_motor_delta1        = 0.0;
double main_motor_delta2        = 0.0;
int    main_motor_volt1         = 512;
int    main_motor_volt2         = 512;

```

```

double      x                = 0.0;
double      y                = 0.0;
double      z                = 0.0;
double      phi              = 0.0; /* degrees */
double      theta            = 0.0; /* degrees */
double      psi              = 0.0; /* degrees */
double      x_dot            = 0.0;
double      y_dot            = 0.0;
double      z_dot            = 0.0;
double      phi_dot          = 0.0; /* degrees/sec */
double      theta_dot        = 0.0; /* degrees/sec */
double      psi_dot          = 0.0; /* degrees/sec */
double      speed            = 0.0;
double      u                = 0.0;
double      v                = 0.0;
double      w                = 0.0;
double      p                = 0.0; /* degrees/sec */
double      q                = 0.0; /* degrees/sec */
double      r                = 0.0; /* degrees/sec */
double      delta_planes    = 0.0; /* degrees */
double      delta_rudder    = 0.0; /* degrees */
double      port_rpm        = 0;
double      stbd_rpm        = 0;
double      vertical_thruster_volts = 0.0;
double      lateral_thruster_volts = 0.0;

unsigned short psi_bit_old    = 0;

double      dg_offset        = 0.0;

double      k_psi            = 0.0;
double      k_r              = 0.0;
double      k_v              = 0.0;

double      k_z              = 0.0;
double      k_w              = 0.0;
double      k_theta          = 0.0;
double      k_q              = 0.0;

double      k_thruster_psi   = 0.0;
double      k_thruster_r     = 0.0;
double      k_thruster_rotate = 0.0;
double      k_thruster_lateral = 0.0;
double      k_thruster_z     = 0.0;
double      k_thruster_w     = 0.0;

double      k_propeller_hover = 0.0;

double      k_surge_hover    = 0.0;

double      k_thruster_hover  = 0.0;
double      k_sway_hover     = 0.0;

double      k_sigma_r        = 12.0;
double      k_sigma_psi      = 28.87;
double      eta_steering     = 0.1;
double      sigma            = 0.0;

int         mission_legs_total = 0;

/* values initialized in parse_mission_script_commands () */
double      time_next_command = 0.0;
double      psi_command       = 0.0; /* degrees */
double      psi_command_hover = 0.0; /* degrees */
double      x_command         = 0.0; /* feet */
double      y_command         = 0.0; /* feet */
double      z_command         = 0.0; /* feet */

```

```

double      stbd_rpm_command      = 0.0;
double      port_rpm_command      = 0.0;
double      planes_command        = 0.0; /* degrees      */
double      rudder_command        = 0.0; /* degrees      */
double      rotate_command        = 0.0; /* degrees/sec  */
double      lateral_command       = 0.0; /* ft/sec       */

double      bow_lateral_thruster_command = 0.0; /* volts -24..24 */
double      stern_lateral_thruster_command = 0.0; /* volts -24..24 */
double      bow_vertical_thruster_command = 0.0; /* volts -24..24 */
double      stern_vertical_thruster_command = 0.0; /* volts -24..24 */

double      waypoint_distance     = 0.0;
double      waypoint_angle        = 0.0;

double      track_angle           = 0.0;
double      along_track_distance  = 0.0;
double      cross_track_distance  = 0.0;
double      standoff_distance     = 10.0;

double      depth_error;

int         roll_rate_0          = 0;
int         pitch_rate_0         = 0;
int         yaw_rate_0           = 0;
int         roll_0               = 0;
int         pitch_0              = 0;
int         z_val0               = 0;
int         sw1                  = 0;
int         error                = 0;
int         range                = 0;
int         bad_rng              = 0;
int         bad_updates          = 0;
int         range_index          = 0;
double      range1               = 0.0;
double      range2               = 0.0;
double      error1               = 0.0;
double      error2               = 0.0;
double      avg_rng              = 0.0;
int         k_range              = 0;
int         range_array [3000];

int         pointer              = NULL;
int         speed_array [11];

int         PortAFlag            = 0.0;

int         tick                 = 0;
int         curr_tick            = 0;
int         tick1                = 0;
int         tick2                = 0;
int         i                    = 0;

int         mask                 = 0x0000ffff;
long        davedate             = 0;
long        davetime             = 0;
double      value                = 0.0;
short       day                  = 0;
char        answer               = ' ';
int         start_dwell          = 0;

int         socket_descriptor    = 0;
int         socket_accepted      = 0;
int         socket_stream        = 0;

int         socket_length        = 255; /* max allowed packet size */

```

```

int          bytes_received      = 0;
int          bytes_read         = 0;
int          bytes_written      = 0;
int          bytes_left         = 0;
int          bytes_sent         = 0;

/* char          buffer_array [FILEBUFFERSIZE][256]; -- not implemented */

char          buffer              [300];
int           buffer_size         = 0;
int           buffer_index       = 0;
int           variables_parsed   = 0;

char          buffer_received     [300],
virtual_world_remote_host_name [60],
command_buffer [300];

FILE          * netstat_fileptr;

struct sockaddr_in server_address;

struct hostent *server_entity;

char          keyword            [81];
char          email_address     [81];

int           shutdown_signal_received = FALSE;
int           virtual_world_socket_opened = FALSE;

char          * ptr_index;

int           print_help         = FALSE;

double        speed_per_rpm = 2.0 / 700.0 ; /* steady state:
                                           2.0 feet/sec per 700 rpm */

clock_t       previousloopclock   = 0;
clock_t       currentloopclock    = 0;

/* +- 24V <=> +-2 lb, + Volts moves thruster in + direction, all identical */
double AUV_bow_vertical   = 0.0; /* thruster rpm */
double AUV_stern_vertical = 0.0; /* thruster rpm */
double AUV_bow_lateral    = 0.0; /* thruster rpm */
double AUV_stern_lateral  = 0.0; /* thruster rpm */

/* warning: do not use leading zero with bearings or else read as octal */
double AUV_ST1000_bearing = 0.0; /* ST_1000 conical pencil bearing */
double AUV_ST1000_range   = 10.0; /* ST_1000 conical pencil range */
double AUV_ST1000_strength = 20.0; /* ST_1000 conical pencil strength */

double AUV_ST725_bearing = 90.0; /* ST_725 1 x 24 sector bearing */
double AUV_ST725_range   = 20.0; /* ST_725 1 x 24 sector range */
double AUV_ST725_strength = 10.0; /* ST_725 1 x 24 sector strength */

int         audible_command = TRUE;

int         auvscriptfilequit = FALSE;

/*****

```

F. *globals.h* Global Variable Define File to Permit Multiple References

```

/*****
/*
Program:          globals.h

Authors:         Don Brutzman

Revised:         28 October 94

System:          AUV Gespac 68020/68030, OS-9 version 2.4
Compiler:        Gespac cc Kernighan & Richie (K&R) C

Compilation:     ftp>      put globals.h
                  auvsim1> chd execution
                  [68020]  auvsim1> make -k2f execution
                  [68030]  auvsim1> make      execution

                  [Irix ]  fltch> make execution

Purpose:         Allows repeated use of global variables global.c via global.h
                  in order to prevent compiler warnings

*/
*****/

#include "defines.h"

/*****
/*
#define GLOBALS_H
*****/

/* Program configuration flags */

extern int      TRACE                ; /* 1=trace on,      0=trace off      */
extern int      DISPLAYSCREEN        ; /* 1=screen on,    0=screen off    */
extern int      LOCATIONLAB          ; /* 1=graphics lab, 0=actual vehicle */
extern int      TACTICAL              ; /* 1=tactical on,  0=tactical off   */
extern int      LOOPFOREVER          ; /* 1=repeat execution indefinitely */
extern int      LOOPFILEBACKUP       ; /* 1=backup files between replications*/

extern int      PARALLELPORTTRACE    ; /* 1=trace each char received at port */
extern int      SONARINSTALLED       ; /* 1=sonar head available for query   */
extern int      SONARTRACE           ; /* 1=trace on,      0=trace off      */
extern int      ENTERCONTROLCONSTANTS ; /* 1>manual entry,  0=default values */
extern int      REALTIME              ; /* 1=1 second real-time waits, 0=none */

extern int      DEADRECKON           ; /* 1=dead reckon navigate, 0=regular */
extern int      DEADSTICKRUDDER      ; /* 1=use ordered rudder, 0 = control */
extern int      DEADSTICKPLANES      ; /* 1=use ordered planes, 0 = control */
extern int      SLIDINGMODECOURSE    ; /* 1=use sliding mode,  0 = control */

extern int      THRUSTERCONTROL      ; /* 1=use thrusters, 0=use propellers */
extern int      ROTATECONTROL         ; /* 1=use thrusters to rotate in place */
extern int      LATERALCONTROL        ; /* 1=use thrusters for lateral motion */
extern int      FOLLOWWAYPOINTMODE    ; /* 1= go to WAYPOINT without WAITS */
extern int      WAYPOINTCONTROL       ; /* 1= go to WAYPOINT */
extern int      HOVERCONTROL          ; /* 1=hover at WAYPOINT */

#if defined(sgi)
extern int      EMAIL                ; /* 1=send e-mail, 0=don't send e-mail */
#else
extern int      EMAIL                ; /* can't send e-mail via OS-9 directly */

```

```

#endif

extern int    NOT_YET_REIMPLEMENTED ; /* code in block needs reverification */

extern double TIMESTEP                ; /* time of a single closed loop      */
                                      /* add code to warn if exceeded <<<< */

extern int    KEYBOARDINPUT           ; /* 1=read keyboard vice mission file */

/*****
/* files and paths
*/

extern FILE * auvscriptfile;
extern FILE * auvordersfile;
extern FILE * auvdatafile;
extern FILE * auvtextfile;
extern FILE * controlconstantsfile;
extern FILE * emailaddressfile;

/* FILE * serialtestfile; */

extern int    serialpath ;

extern int    sonarpath ;

/*****
/* Variables and data structures
*/

/* buffers of full strings for byte transfer to tactical level & disk file */
/* 'buffer' usually < 256, intentionally oversized in case of overflow error */

extern time_t      system_time      ;
extern struct tm   *system_tm       ;

/* partial structure template for the MFI (only interested in PIA for now) */

struct MFI_PIA
{
    unsigned short pra;          /* port    register A - data direction A */
    unsigned short cra;          /* control register A
    */
    unsigned short prb;          /* port    register B - data direction B */
    unsigned short crb;          /* control register B
    */
};

/* 4 Channels of DAC ADA-1 DAC
extern unsigned char *dac1_a ;

/* 8 Channels of DAC DAC-2B
extern unsigned char *dac2b_a ;

/* 16 Channels of ADC ADA-1
extern unsigned char *adc1_a ;

/* 16 Channels of ADC ADC-2
extern unsigned short *adc2_a ;

extern unsigned short *via0 ;

extern int      telemetry_records_saved ;
extern int      mission_leg_counter;
extern int      replication_count      ;
extern int      end_test                ;
extern int      wrap_count              ;
extern double   t                        ;
extern double   dt                       ;
extern double   rpm;
extern double   speed_limit              ;

```

```

extern double      main_motor_delta1      ;
extern double      main_motor_delta2      ;
extern int         main_motor_volt1       ;
extern int         main_motor_volt2       ;

extern double      x                      ;
extern double      y                      ;
extern double      z                      ;
extern double      phi                    ; /* degrees */
extern double      theta                  ; /* degrees */
extern double      psi                    ; /* degrees */
extern double      x_dot                  ;
extern double      y_dot                  ;
extern double      z_dot                  ;
extern double      phi_dot                ; /* degrees/sec */
extern double      theta_dot              ; /* degrees/sec */
extern double      psi_dot                ; /* degrees/sec */
extern double      speed                  ;
extern double      u                      ;
extern double      v                      ;
extern double      w                      ;
extern double      p                      ; /* degrees/sec */
extern double      q                      ; /* degrees/sec */
extern double      r                      ; /* degrees/sec */
extern double      delta_planes           ; /* degrees */
extern double      delta_rudder           ; /* degrees */
extern double      port_rpm              ;
extern double      stbd_rpm              ;
extern double      vertical_thruster_volts ;
extern double      lateral_thruster_volts ;

extern unsigned short psi_bit_old        ;

extern double      dg_offset              ;

extern double      k_psi                  ;
extern double      k_r                    ;
extern double      k_v                    ;

extern double      k_z                    ;
extern double      k_w                    ;
extern double      k_theta                ;
extern double      k_q                    ;

extern double      k_thruster_psi         ;
extern double      k_thruster_r           ;
extern double      k_thruster_rotate      ;
extern double      k_thruster_lateral     ;
extern double      k_thruster_z           ;
extern double      k_thruster_w           ;

extern double      k_propeller_hover       ;

extern double      k_surge_hover           ;

extern double      k_thruster_hover       ;
extern double      k_sway_hover           ;

extern double      k_sigma_r              ;
extern double      k_sigma_psi            ;
extern double      eta_steering            ;
extern double      sigma                  ;

extern int         mission_legs_total     ;

/*      values initialized in parse_mission_script_commands () */
extern double      time_next_command      ;

```

```

extern double      psi_command      ; /* degrees      */
extern double      psi_command_hover ; /* degrees      */
extern double      x_command        ; /* feet         */
extern double      y_command        ; /* feet         */
extern double      z_command        ; /* feet         */
extern double      stbd_rpm_command ;
extern double      port_rpm_command ;
extern double      planes_command   ; /* degrees      */
extern double      rudder_command   ; /* degrees      */
extern double      rotate_command   ; /* degrees/sec  */
extern double      lateral_command   ; /* ft/sec       */

extern double      bow_lateral_thruster_command ; /* volts -24..24 */
extern double      stern_lateral_thruster_command ; /* volts -24..24 */
extern double      bow_vertical_thruster_command ; /* volts -24..24 */
extern double      stern_vertical_thruster_command ; /* volts -24..24 */

extern double      waypoint_distance ;
extern double      waypoint_angle    ;

extern double      track_angle        ;
extern double      along_track_distance ;
extern double      cross_track_distance ;
extern double      standoff_distance  ;

extern double      depth_error;

extern int         roll_rate_0        ;
extern int         pitch_rate_0       ;
extern int         yaw_rate_0         ;
extern int         roll_0             ;
extern int         pitch_0            ;
extern int         z_val0             ;
extern int         swl                ;
extern int         error              ;
extern int         range              ;
extern int         bad_rng            ;
extern int         bad_updates        ;
extern int         range_index        ;
extern double      range1             ;
extern double      range2             ;
extern double      error1             ;
extern double      error2             ;
extern double      avg_rng            ;
extern int         k_range            ;
extern int         range_array [3000];

extern int         pointer            ;
extern int         speed_array [11]   ;

extern int         PortAFlag         ;

extern int         tick              ;
extern int         curr_tick         ;
extern int         tick1             ;
extern int         tick2             ;
extern int         i                 ;

extern int         mask              ;
extern long        davedate          ;
extern long        davetime          ;
extern double      value             ;
extern short       day               ;
extern char        answer            ;
extern int         start_dwell       ;

extern int         socket_descriptor ;

```

```

extern int          socket_accepted      ;
extern int          socket_stream        ;

extern int          socket_length        ; /* max allowed packet size */

extern int          bytes_received        ;
extern int          bytes_read           ;
extern int          bytes_written        ;
extern int          bytes_left           ;
extern int          bytes_sent           ;

/* char          buffer_array [FILEBUFFERSIZE][256]; -- not implemented */

extern char          buffer              [300];
extern int          buffer_size          ;
extern int          buffer_index         ;
extern int          variables_parsed     ;

extern char          buffer_received     [300],
                  virtual_world_remote_host_name [60],
                  command_buffer        [300];

extern FILE          * netstat_fileptr;

extern struct sockaddr_in server_address;

extern struct hostent *server_entity;

extern char          keyword             [81];
extern char          email_address       [81];

extern int          shutdown_signal_received ;
extern int          virtual_world_socket_opened ;

extern char          * ptr_index;

extern int          print_help;

extern double        speed_per_rpm; /* steady state: 2.0 feet/sec per 700 rpm */

extern clock_t        previousloopclock;
extern clock_t        currentloopclock;

/* +- 24V <=> +-2 lb, + Volts moves thruster in + direction, all identical */
extern double AUV_bow_vertical ; /* thruster rpm */
extern double AUV_stern_vertical ; /* thruster rpm */
extern double AUV_bow_lateral ; /* thruster rpm */
extern double AUV_stern_lateral ; /* thruster rpm */

/* warning: do not use leading zero with bearings or else read as octal */
extern double AUV_ST1000_bearing ; /* ST_1000 conical pencil bearing */
extern double AUV_ST1000_range ; /* ST_1000 conical pencil range */
extern double AUV_ST1000_strength; /* ST_1000 conical pencil strength*/

extern double AUV_ST725_bearing ; /* ST_725 1 x 24 sector bearing */
extern double AUV_ST725_range ; /* ST_725 1 x 24 sector range */
extern double AUV_ST725_strength ; /* ST_725 1 x 24 sector strength */

extern int        audible_command ;

extern int        auvscriptfilequit ;

/*****
#endif

```

G. *Makefile.OS9* for Execution Level under OS-9 Operating System

```
# AUV execution level Makefile.OS9

# Don Brutzman 27 OCT 94

# modified OS-9 makefile (originally from /h0/INET/SOURCE/)
# this Makefile is necessary to resolve network libraries compilation

# Note that OS-9 Make syntax is nonstandard.

DD      = /h0
LIB      = -l$(DD)/lib/sys.l
SOCKLIB  = ../lib/socklib.l
NETLIB   = ../lib/netdb.l
#RDIR    = RELS
RDIR     = .
ODIR     = $(DD)/cmds
RFLAGS   =
CFLAGS   = -bp -g

SOURCE   = recv_str      xmit_str      os9sender      os9server
RSOURCE  = recv_str.r    xmit_str.r    os9sender.r    os9server.r

make.date: $(SOURCE)
        touch make.date

globals: $(SOCKLIB) $(NETLIB) globals.c globals.h defines.h Makefile
        cc $(CFLAGS) globals.c -r -l../$(NETLIB) -l../$(SOCKLIB) $(LIB)

parse_functions: $(SOCKLIB) $(NETLIB) parse_functions.c globals.h defines.h
Makefile
        cc $(CFLAGS) parse_functions.c -r -l../$(NETLIB) -l../$(SOCKLIB) $(LIB)

execution: $(SOCKLIB) $(NETLIB) globals.r parse_functions.r      execution.c
globals.h defines.h Makefile
        cc $(CFLAGS) execution.c globals.r parse_functions.r -f=execution \
        -l../$(NETLIB) -l../$(SOCKLIB) $(LIB) -lm

# clean:
#       rm *.r /h0/CMDS/execution

# old versions
# -k=0 68000 (default)
# -k=2 68020
# -t=/r0      puts temporary files in ramdisk and speeds compilation
# $*.r        saves relocatable modules in RDIR
# $(SOURCE): $(SOCKLIB) $(NETLIB)
#       cc $(CFLAGS) $*.r -f=$* -l../$(NETLIB) -l../$(SOCKLIB) $(LIB)
#       cc $(CFLAGS) execution.c -r      -l../$(NETLIB) -l../$(SOCKLIB) $(LIB)
```

H. *Makefile.SGI* for Execution Level under SGI Irix 5.2 Operating System

```
# ATW execution level Makefile.sgi
# Don Brutzman 27 OCT 94

execution: globals.c parse_functions.c execution.c globals.h defines.h Makefile
        cc      -g -lm -cckr -w      \
        globals.c parse_functions.c execution.c -o execution

# The 'warnings' make option gives voluminous diagnostics which are useful
# in preventing mysterious bugs when the execution code is ported to OS-9.
# Similar to lint.

warnings:
        cc      -g -lm -cckr -fullwarn -wlint,p \
        globals.c parse_functions.c execution.c -o execution

all:
        touch globals.c parse_functions.c execution.c
        make execution

clean:
        rm execution *.o
```

I. *startup OS-9 Reboot System Configuration File*

```
-t -np
*
* OS-9 startup file
* Last modification 22 JUN 94      Walt Landaker & Don Brutzman
*
*
*
setime -s                      ;* start system clock
link shell cio                 ;* make "shell" and "cio" stay in memory

* the following are already in RAM memory from hard disk bootfile /h0/OS9boot
* in iz r0 h0 d0 t1 p1        ;* initialize devices
* load utils                   ;* make some utilities stay in memory
* load bootobjs/dd.r0          ;* get the default device descriptor
* init ramdisk >/nil >>/nil&   ;* initialize it if its the ram disk
* tsmom /t1 &                  ;* start other terminals

setenv TERM vt100
startlan
wait
free
list sys/motd
shell ->>/term -e=/h0/sys/errmsg.short
login
```

J. *.login* OS-9 User Login and Unix Alias File

```
# auvsim1 .login file
# for OS-9 with 'sh' shell
# Don Brutzman 22 June 94

history 40
setenv TERM vt100

alias cat      list
alias cd       chd
alias chmod    attr -?
alias clear    cls
alias cp       copy
alias h        history
alias l        dir -ade
alias ls       dir -ad
alias m        list
alias man      help
alias mkdir    makdir
alias more     list
alias lo       logout
alias nopause  tmode nopause
alias pause    tmode pause
alias ps       procs
alias pwd      pd
alias quit     logout
alias reboot   shell break
alias ren      rename
alias rm       del
alias rmdir    deldir
alias s        sh
alias source   sh
alias type     list

# following doesn't seem to work
#   automatically on telnet logins
tmode nopause

echo
echo "telnet users type: nopause"
```

K. *auv_plot.gnu*: Execution Level Telemetry Plotting using *gnuplot*

```
*****
#
# filename: auv_plot.gnu
#
# function: GNUPLOT V3.5 script to plot AUV telemetry data
#           to screen & to PostScript files
#
# updated: 18 OCT 94
#
# author: Don Brutzman
#
# execution: gnuplot> load "auv_plot.gnu"
#            gnuplot> reread
#
#            unix> gnuplot auv_plot.gnu
#
# re-plotting:
# 'xpsview' -wp -skipc -or landscape ~/execution/AUV_telemetry.ps &
# ghostview -landscape ~/execution/AUV_telemetry.ps &
#
# C program call: system ("gnuplot auv_plot.gnu");
#
# telemetry: mission.output.telemetry (AUV telemetry 0.1 sec interval)
# alternate: mission.output.1_second (AUV telemetry 1.0 sec interval)
#
# alternate plot: unix> gnuplot auv_plot_1_second.gnu
#
# output files: AUV_telemetry.ps & *.eps plots
#
# related files: execution.c
#                underwater virtual world
#
# output archive: ftp://taurus.cs.nps.navy.mil/pub/auv/AUV_telemetry.ps.Z
#
# gnuplot FAQ:    ftp://ftp.dartmouth.edu/pub/gnuplot/faq/gpt_faq.html
#
# distribution:   http://www.cs.dartmouth.edu/gnuplot/
*****
```

* Plot filenames:

```
* combined AUV_telemetry.ps
* figure 1 AUV_x.y.eps
* figure 2 AUV_t_x.eps
* figure 3 AUV_t_y.eps
* figure 4 AUV_t_z.eps
* figure 5 AUV_t_phi.eps
* figure 6 AUV_t_theta.eps
* figure 7 AUV_t_theta_all.eps
* figure 8 AUV_t_psi.eps
* figure 9 AUV_t_lateral_thrusters.eps
* figure 10 AUV_t_vertical_thrusters.eps
* figure 11 AUV_t_u.eps
* figure 12 AUV_t_v.eps
* figure 13 AUV_t_w.eps
* figure 14 AUV_t_p.eps
* figure 15 AUV_t_q.eps
* figure 16 AUV_t_r.eps
* figure 17 AUV_t_delta_rudder.eps
* figure 18 AUV_t_delta_planes.eps
* figure 19 AUV_t_rpm.eps
* figure 20 AUV_t_thrusters.eps
```

* setup:

```
set terminal x11
set time
set grid
```

```

set data style linespoints

set samples 10          * data point plotting frequency

#####

set xlabel "East -> (y_world) [ft]"
set ylabel "North ^ (x_world) [ft]"

set title "NPS AUV telemetry 1" 26,.8
plot "mission.output.telemetry" using 4:3 title "x vs y (geographic position plot)"
pause -1 "hit enter to continue with plot 2"

set xlabel "time t (seconds)"
set ylabel

set title "NPS AUV telemetry 2" 26,.8
plot "mission.output.telemetry" using 2:3 title "t vs x [ft]" , \
     "mission.output.telemetry" using 2:15 title "t vs x_dot [ft/sec]"
pause -1 "hit enter to continue with plot 3"

set title "NPS AUV telemetry 3" 26,.8
plot "mission.output.telemetry" using 2:4 title "t vs y [ft]" , \
     "mission.output.telemetry" using 2:16 title "t vs y_dot [ft/sec]"
pause -1 "hit enter to continue with plot 4"

set title "NPS AUV telemetry 4" 26,.8
plot "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]" , \
     "mission.output.telemetry" using 2:17 title "t vs z_dot (depth rate) [ft/sec]" , \
     "mission.output.telemetry" using 2:22 title "t vs delta_planes [deg]" , \
     "mission.output.orders" using 1:3 title "t vs ordered depth [ft]" * with steps
pause -1 "hit enter to continue with plot 5"

set title "NPS AUV telemetry 5" 26,.8
plot "mission.output.telemetry" using 2:6 title "t vs phi (roll: x axis) [deg]" , \
     "mission.output.telemetry" using 2:18 title "t vs phi_dot (roll rate) [deg/sec]"
pause -1 "hit enter to continue with plot 6"

set title "NPS AUV telemetry 6" 26,.8
plot "mission.output.telemetry" using 2:7 title "t vs theta (elevation angle) [deg]" , \
     "mission.output.telemetry" using 2:19 title "t vs theta_dot (elevation rate) [deg/sec]"
pause -1 "hit enter to continue with plot 7"

set title "NPS AUV telemetry 7" 26,.8
plot "mission.output.telemetry" using 2:7 title "t vs theta (elevation angle) [deg]" , \
     "mission.output.telemetry" using 2:19 title "t vs theta_dot (elevation rate) [deg/sec]" , \
     "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]" , \
     "mission.output.telemetry" using 2:11 title "t vs w (heave) [ft/sec]" , \
     "mission.output.telemetry" using 2:22 title "t vs delta_planes [deg]" , \
     "mission.output.orders" using 1:3 title "t vs ordered depth [ft]" * with steps
steps
pause -1 "hit enter to continue with plot 8"

set title "NPS AUV telemetry 8" 26,.8
plot "mission.output.telemetry" using 2:8 title "t vs psi (azimuth: z axis) [deg]" , \
     "mission.output.telemetry" using 2:20 title "t vs psi_dot (azimuth rate) [deg/sec]" , \
     "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]" , \
     "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]" , \
     "mission.output.orders" using 1:2 title "t vs ordered heading [deg]" * with steps
pause -1 "hit enter to continue with plot 9"

set title "NPS AUV telemetry 9" 26,.8
plot "mission.output.telemetry" using 2:8 title "t vs psi (azimuth: z axis) [deg]" , \
     "mission.output.telemetry" using 2:20 title "t vs psi_dot (azimuth rate) [deg/sec]" , \
     "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]" , \
     "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]" , \
     "mission.output.telemetry" using 2:27 title "t vs bow lateral thruster [volts]" * with steps
steps, \
"mission.output.telemetry" using 2:28 title "t vs stern lateral thruster [volts]" * with steps
steps, \
"mission.output.orders" using 1:2 title "t vs ordered heading [deg]" * with steps
pause -1 "hit enter to continue with plot 10"

set title "NPS AUV telemetry 10" 26,.8
plot "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]" , \

```

```

    "mission.output.telemetry"      using 2:11 title "t vs w (heave) [ft/sec]", \
    "mission.output.telemetry"      using 2:25 title "t vs bow vertical thruster [volts]" with steps, \
    "mission.output.telemetry"      using 2:26 title "t vs stern vertical thruster [volts]" with steps, \
    "mission.output.orders"         using 1:3 title "t vs ordered depth [ft]" with steps
pause -1 "hit enter to continue with plot 11"

set title "NPS AUV telemetry 11" 26,.8
plot "mission.output.telemetry" using 2:9 title "t vs u (surge) [ft/sec]"
pause -1 "hit enter to continue with plot 12"

set title "NPS AUV telemetry 12" 26,.8
plot "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]"
pause -1 "hit enter to continue with plot 13"

set title "NPS AUV telemetry 13" 26,.8
plot "mission.output.telemetry" using 2:11 title "t vs w (heave) [ft/sec]"
pause -1 "hit enter to continue with plot 14"

set title "NPS AUV telemetry 14" 26,.8
plot "mission.output.telemetry" using 2:12 title "t vs p (roll rate) [deg/sec]"
pause -1 "hit enter to continue with plot 15"

set title "NPS AUV telemetry 15" 26,.8
plot "mission.output.telemetry" using 2:13 title "t vs q (pitch rate) [deg/sec]"
pause -1 "hit enter to continue with plot 16"

set title "NPS AUV telemetry 16" 26,.8
plot "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]"
pause -1 "hit enter to continue with plot 17"

set title "NPS AUV telemetry 17" 26,.8
plot "mission.output.telemetry" using 2:21 title "t vs delta_rudder bow [deg]"
pause -1 "hit enter to continue with plot 18"

set title "NPS AUV telemetry 18" 26,.8
plot "mission.output.telemetry" using 2:22 title "t vs delta_planes bow [deg]"
pause -1 "hit enter to continue with plot 19"

set title "NPS AUV telemetry 19" 26,.8
plot "mission.output.telemetry" using 2:23 title "t vs rpm_left [rpm]", \
    "mission.output.telemetry" using 2:24 title "t vs rpm_right [rpm]", \
    "mission.output.orders" using 1:4 title "t vs rpm_ordered [rpm]" with steps
pause -1 "hit enter to continue with plot 20"

set title "NPS AUV telemetry 20" 26,.8
plot "mission.output.telemetry" using 2:25 title "t vs bow vertical thruster [volts]" with steps, \
    "mission.output.telemetry" using 2:26 title "t vs stern vertical thruster [volts]" with steps, \
    "mission.output.telemetry" using 2:27 title "t vs bow lateral thruster [volts]" with steps, \
    "mission.output.telemetry" using 2:28 title "t vs stern lateral thruster [volts]" with steps

pause -1 "hit enter to plot postscript files & quit"

*****
*****

pause 0 "plotting combined plot AUV_telemetry.ps ..."

clear

# -----#
# uncomment to choose one of the following two options:
# -----#
# 60% size for xpsview
# set size 0.6, 0.6
# set terminal postscript portrait color "Courier" 14
# set title "NPS AUV telemetry" 29,.8
# -----#
# full page for printing
# set terminal postscript landscape color "Courier" 20
# set title "NPS AUV telemetry" 16,.8
# -----#

set output "AUV_telemetry.ps"

pause 0 "page 1"
set xlabel "East -> (y_world) [ft]"

```

```

set ylabel "North -> (x_world) [ft]"
set title "NPS AUV telemetry 1" 14,.8
plot "mission.output.telemetry" using 4:3 title "x vs y (geographic position plot)"

set xlabel "time t (seconds)"
set ylabel

pause 0 "page 2"
set title "NPS AUV telemetry 2" 14,.8
plot "mission.output.telemetry" using 2:3 title "t vs x [ft]" , \
      "mission.output.telemetry" using 2:15 title "t vs x_dot [ft/sec]"

pause 0 "page 3"
set title "NPS AUV telemetry 3" 14,.8
plot "mission.output.telemetry" using 2:4 title "t vs y [ft]" , \
      "mission.output.telemetry" using 2:16 title "t vs y_dot [ft/sec]"

pause 0 "page 4"
set title "NPS AUV telemetry 4" 14,.8
plot "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]" , \
      "mission.output.telemetry" using 2:17 title "t vs z_dot (depth rate) [ft/sec]" , \
      "mission.output.telemetry" using 2:22 title "t vs delta_planes [deg]" , \
      "mission.output.orders" using 1:3 title "t vs ordered depth [ft]" * with steps

pause 0 "page 5"
set title "NPS AUV telemetry 5" 14,.8
plot "mission.output.telemetry" using 2:6 title "t vs phi (roll: x axis) [deg]" , \
      "mission.output.telemetry" using 2:18 title "t vs phi_dot (roll rate) [deg/sec]"

pause 0 "page 6"
set title "NPS AUV telemetry 6" 14,.8
plot "mission.output.telemetry" using 2:7 title "t vs theta (elevation angle) [deg]" , \
      "mission.output.telemetry" using 2:19 title "t vs theta_dot (elevation rate) [deg/sec]"

pause 0 "page 7"
set title "NPS AUV telemetry 7" 14,.8
plot "mission.output.telemetry" using 2:7 title "t vs theta (elevation angle) [deg]" , \
      "mission.output.telemetry" using 2:19 title "t vs theta_dot (elevation rate) [deg/sec]" , \
      "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]" , \
      "mission.output.telemetry" using 2:11 title "t vs w (heave) [ft/sec]" , \
      "mission.output.telemetry" using 2:22 title "t vs delta_planes [deg]" , \
      "mission.output.orders" using 1:3 title "t vs ordered depth [ft]" * with steps

steps

pause 0 "page 8"
set title "NPS AUV telemetry 8" 14,.8
plot "mission.output.telemetry" using 2:8 title "t vs psi (azimuth: z axis) [deg]" , \
      "mission.output.telemetry" using 2:20 title "t vs psi_dot (azimuth rate) [deg/sec]" , \
      "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]" , \
      "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]" , \
      "mission.output.telemetry" using 2:21 title "t vs delta_rudder [deg]" , \
      "mission.output.orders" using 1:2 title "t vs ordered heading [deg]" * with steps

pause 0 "page 9"
set title "NPS AUV telemetry 9" 14,.8
plot "mission.output.telemetry" using 2:8 title "t vs psi (azimuth: z axis) [deg]" , \
      "mission.output.telemetry" using 2:20 title "t vs psi_dot (azimuth rate) [deg/sec]" , \
      "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]" , \
      "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]" , \
      "mission.output.telemetry" using 2:27 title "t vs bow lateral thruster [volts]" * with steps, \
steps, \
      "mission.output.telemetry" using 2:28 title "t vs stern lateral thruster [volts]" * with steps, \
steps, \
      "mission.output.orders" using 1:2 title "t vs ordered heading [deg]" * with steps

pause 0 "page 10"
set title "NPS AUV telemetry 10" 14,.8
plot "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]" , \
      "mission.output.telemetry" using 2:11 title "t vs w (heave) [ft/sec]" , \
      "mission.output.telemetry" using 2:25 title "t vs bow vertical thruster [volts]" * with steps, \
      "mission.output.telemetry" using 2:26 title "t vs stern vertical thruster [volts]" * with steps, \
      "mission.output.orders" using 1:3 title "t vs ordered depth [ft]" * with steps

pause 0 "page 11"
set title "NPS AUV telemetry 11" 14,.8
plot "mission.output.telemetry" using 2:9 title "t vs u (surge) [ft/sec]"

```

```

pause 0 "page 12"
set title "NPS AUV telemetry 12" 14,.8
plot "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]"

pause 0 "page 13"
set title "NPS AUV telemetry 13" 14,.8
plot "mission.output.telemetry" using 2:11 title "t vs w (heave) [ft/sec]"

pause 0 "page 14"
set title "NPS AUV telemetry 14" 14,.8
plot "mission.output.telemetry" using 2:12 title "t vs p (roll rate) [deg/sec]"

pause 0 "page 15"
set title "NPS AUV telemetry 15" 14,.8
plot "mission.output.telemetry" using 2:13 title "t vs q (pitch rate) [deg/sec]"

pause 0 "page 16"
set title "NPS AUV telemetry 16" 14,.8
plot "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]"

pause 0 "page 17"
set title "NPS AUV telemetry 17" 14,.8
plot "mission.output.telemetry" using 2:21 title "t vs delta_rudder bow [deg]"

pause 0 "page 18"
set title "NPS AUV telemetry 18" 14,.8
plot "mission.output.telemetry" using 2:22 title "t vs delta_planes bow [deg]"

pause 0 "page 19"
set title "NPS AUV telemetry 19" 14,.8
plot "mission.output.telemetry" using 2:23 title "t vs rpm_left [rpm]", \
     "mission.output.telemetry" using 2:24 title "t vs rpm_right [rpm]", \
     "mission.output.orders" using 1:4 title "t vs rpm_ordered [rpm]" with steps

pause 0 "page 20"
set title "NPS AUV telemetry 20" 14,.8
plot "mission.output.telemetry" using 2:25 title "t vs bow vertical thruster [volts]" with steps, \
     "mission.output.telemetry" using 2:26 title "t vs stern vertical thruster [volts]" with steps, \
     "mission.output.telemetry" using 2:27 title "t vs bow lateral thruster [volts]" with steps, \
     "mission.output.telemetry" using 2:28 title "t vs stern lateral thruster [volts]" with steps

*****
*****

pause 0 "plotting individual encapsulated postscript files..."

set title "NPS AUV telemetry" 29,.8

set terminal postscript eps color "Courier" 14

pause 0 "figure 1 AUV_x_y.eps"
set output "AUV_x_y.eps"
set xlabel "East -> (y_world) [ft]"
set ylabel "North -> (x_world) [ft]"
set title "NPS AUV telemetry 1" 26,.8
plot "mission.output.telemetry" using 4:3 title "x vs y (geographic position plot)"

set xlabel "time t (seconds)"
set ylabel

pause 0 "figure 2 AUV_t_x.eps"
set output "AUV_t_x.eps"
set title "NPS AUV telemetry 2" 26,.8
plot "mission.output.telemetry" using 2:3 title "t vs x [ft]", \
     "mission.output.telemetry" using 2:15 title "t vs x_dot [ft/sec]"

pause 0 "figure 3 AUV_t_y.eps"
set output "AUV_t_y.eps"
set title "NPS AUV telemetry 3" 26,.8
plot "mission.output.telemetry" using 2:4 title "t vs y [ft]", \
     "mission.output.telemetry" using 2:16 title "t vs y_dot [ft/sec]"

pause 0 "figure 4 AUV_t_z.eps"
set output "AUV_t_z.eps"
set title "NPS AUV telemetry 4" 26,.8
plot "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]", \

```

```

"mission.output.telemetry"      using 2:17 title "t vs z_dot (depth rate) [ft/sec]", \
"mission.output.telemetry"      using 2:22 title "t vs delta_planes [deg]", \
"mission.output.orders"         using 1:3 title "t vs ordered depth [ft]" * with steps

pause 0 "figure 5 AUV_t_phi.eps"
set output "AUV_t_phi.eps"
set title "NPS AUV telemetry 5" 26,.8
plot "mission.output.telemetry" using 2:6 title "t vs phi (roll: x axis) [deg]", \
"mission.output.telemetry"      using 2:18 title "t vs phi_dot (roll rate) [deg/sec]"

pause 0 "figure 6 AUV_t_theta.eps"
set output "AUV_t_theta.eps"
set title "NPS AUV telemetry 6" 26,.8
plot "mission.output.telemetry" using 2:7 title "t vs theta (elevation angle) [deg]", \
"mission.output.telemetry"      using 2:19 title "t vs theta_dot (elevation rate) [deg/sec]"

pause 0 "figure 7 AUV_t_theta_all.eps"
set output "AUV_t_theta_all.eps"
set title "NPS AUV telemetry 7" 26,.8
plot "mission.output.telemetry" using 2:7 title "t vs theta (elevation angle) [deg]", \
"mission.output.telemetry"      using 2:19 title "t vs theta_dot (elevation rate) [deg/sec]", \
"mission.output.telemetry"      using 2:5 title "t vs z (depth) [ft]", \
"mission.output.telemetry"      using 2:11 title "t vs w (heave) [ft/sec]", \
"mission.output.telemetry"      using 2:22 title "t vs delta_planes [deg]", \
"mission.output.orders"         using 1:3 title "t vs ordered depth [ft]" * with steps
steps

pause 0 "figure 8 AUV_t_psi.eps"
set output "AUV_t_psi.eps"
set title "NPS AUV telemetry 8" 26,.8
plot "mission.output.telemetry" using 2:8 title "t vs psi (azimuth: z axis) [deg]", \
"mission.output.telemetry"      using 2:20 title "t vs psi_dot (azimuth rate) [deg/sec]", \
"mission.output.telemetry"      using 2:14 title "t vs r (yaw rate) [deg/sec]", \
"mission.output.telemetry"      using 2:10 title "t vs v (sway) [ft/sec]", \
"mission.output.telemetry"      using 2:21 title "t vs delta_rudder [deg]", \
"mission.output.orders"         using 1:2 title "t vs ordered heading [deg]" * with steps

pause 0 "figure 9 AUV_t_lateral_thrusters.eps"
set output "AUV_t_lateral_thrusters.eps"
set title "NPS AUV telemetry 9" 26,.8
plot "mission.output.telemetry" using 2:8 title "t vs psi (azimuth: z axis) [deg]", \
"mission.output.telemetry"      using 2:20 title "t vs psi_dot (azimuth rate) [deg/sec]", \
"mission.output.telemetry"      using 2:14 title "t vs r (yaw rate) [deg/sec]", \
"mission.output.telemetry"      using 2:10 title "t vs v (sway) [ft/sec]", \
"mission.output.telemetry"      using 2:27 title "t vs bow lateral thruster [volts]" * with steps
steps,
"mission.output.telemetry"      using 2:28 title "t vs stern lateral thruster [volts]" * with steps
steps,
"mission.output.orders"         using 1:2 title "t vs ordered heading [deg]" * with steps

pause 0 "figure 10 AUV_t_vertical_thrusters.eps"
set output "AUV_t_vertical_thrusters.eps"
set title "NPS AUV telemetry 10" 26,.8
plot "mission.output.telemetry" using 2:5 title "t vs z (depth) [ft]", \
"mission.output.telemetry"      using 2:11 title "t vs w (heave) [ft/sec]", \
"mission.output.telemetry"      using 2:25 title "t vs bow vertical thruster [volts]" * with steps, \
"mission.output.telemetry"      using 2:26 title "t vs stern vertical thruster [volts]" * with steps, \
"mission.output.orders"         using 1:3 title "t vs ordered depth [ft]" * with steps

pause 0 "figure 11 AUV_t_u.eps"
set output "AUV_t_u.eps"
set title "NPS AUV telemetry 11" 26,.8
plot "mission.output.telemetry" using 2:9 title "t vs u (surge) [ft/sec]"

pause 0 "figure 12 AUV_t_v.eps"
set output "AUV_t_v.eps"
set title "NPS AUV telemetry 12" 26,.8
plot "mission.output.telemetry" using 2:10 title "t vs v (sway) [ft/sec]"

pause 0 "figure 13 AUV_t_w.eps"
set output "AUV_t_w.eps"
set title "NPS AUV telemetry 13" 26,.8
plot "mission.output.telemetry" using 2:11 title "t vs w (heave) [ft/sec]"

pause 0 "figure 14 AUV_t_p.eps"
set output "AUV_t_p.eps"

```

```

set title "NPS AUV telemetry 14" 26,.8
plot "mission.output.telemetry" using 2:12 title "t vs p (roll rate) [deg/sec]"

pause 0 "figure 15 AUV_t_q.eps"
set output "AUV_t_q.eps"
set title "NPS AUV telemetry 15" 26,.8
plot "mission.output.telemetry" using 2:13 title "t vs q (pitch rate) [deg/sec]"

pause 0 "figure 16 AUV_t_r.eps"
set output "AUV_t_r.eps"
set title "NPS AUV telemetry 16" 26,.8
plot "mission.output.telemetry" using 2:14 title "t vs r (yaw rate) [deg/sec]"

pause 0 "figure 17 AUV_t_delta_rudder.eps"
set output "AUV_t_delta_rudder.eps"
set title "NPS AUV telemetry 17" 26,.8
plot "mission.output.telemetry" using 2:21 title "t vs delta_rudder bow [deg]"

pause 0 "figure 18 AUV_t_delta_planes.eps"
set output "AUV_t_delta_planes.eps"
set title "NPS AUV telemetry 18" 26,.8
plot "mission.output.telemetry" using 2:22 title "t vs delta_planes bow [deg]"

pause 0 "figure 19 AUV_t_rpm.eps"
set output "AUV_t_rpm.eps"
set title "NPS AUV telemetry 19" 26,.8
plot "mission.output.telemetry" using 2:23 title "t vs rpm_left [rpm]", \
     "mission.output.telemetry" using 2:24 title "t vs rpm_right [rpm]", \
     "mission.output.orders" using 1:4 title "t vs rpm_ordered [rpm]" with steps

pause 0 "figure 20 AUV_t_thrusters.eps"
set output "AUV_t_thrusters.eps"
set title "NPS AUV telemetry 20" 26,.8
plot "mission.output.telemetry" using 2:25 title "t vs bow vertical thruster [volts]" with steps, \
     "mission.output.telemetry" using 2:26 title "t vs stern vertical thruster [volts]" with steps, \
     "mission.output.telemetry" using 2:27 title "t vs bow lateral thruster [volts]" with steps, \
     "mission.output.telemetry" using 2:28 title "t vs stern lateral thruster [volts]" with steps

*****

pause 0 "gnuplot auv_plot.gnu complete."

```

IV. UNDERWATER VIRTUAL WORLD GRAPHICS

A. Introduction

The Open Inventor 2.0 applications program interface (API) is used for generating 3D computer graphics images representing the virtual world (Wernecke 94a, 94b). Open Inventor was chosen for the virtual world graphics engine due to its being built upon the Open GL graphics language, expected portability to multiple hardware architectures and operating systems, SGI-standard scene description language, object-oriented design, broad flexibility and strong support. The Open Inventor scene description language (*.iv*) is likely to become a compatible standard with numerous graphics engines and the nascent Virtual Reality Modeling Language (*.vrmf*), a research extension to Hypertext Markup Language (*.html*).

Embedded in the graphics viewer code is a Distributed Interactive Simulation (DIS) 2.0.3 multicast network API which permits *viewer* to receive robot update information nearly anywhere the Internet via the Multicast Backbone (MBone). After the configuration file *.sd.tcl* is installed, the *viewer* program can be launched automatically via the MBone session directory (*sd*) advertisement application, enabling simple remote *viewer* execution and connection to an already-running virtual world. Future work includes adding a WWW-compatible scene and object loader, and the capability to receive URLs for retrieval, either via DIS updates or from objects encountered by the robot that are already in the scene graph.

B. **viewer.C Object-Oriented Real-Time 3D Computer Graphics Viewing Program using Open Inventor 2.0**

```
////////////////////////////////////
/*
Program:      viewer.C

Description:   Open Inventor viewer for
              NPS AUV Underwater Virtual World

Author:       Don Brutzman

Revised:      28 October 94

System:       Irix 5.2

Compiler:     ANSI C++ / Open Inventor API

Compilation:  irix> make viewer

References: (1) IEEE Protocols for Distributed Interactive Simulation (DIS)
              Applications version 2.0, Institute for Simulation and
              Training, Universit of Central Florida, Orlando Florida,
              28 May 1993.

              (2) Macedonia, Michael, Zeswitz, Steven, and Locke, John,
              Distributed Interactive Simulation (DIS) multicast
              version 2.0.3, Naval Postgraduate School, February 94.

              (3) Zeswitz, Steven, "NPSNET: Integration of Distributed
              Interactive Simulation (DIS) Protocol for Communication
              Architecture and Information Interchange." master's thesis,
              Naval Postgraduate School, Monterey California, 28 May 1993.

              (4) Wernecke, Josie and the Open Inventor Architecture Group,
              _The Inventor Mentor_, Addison-Wesley, Reading Massachusetts,
              1994.

Advisors:     Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

Notes:        Underwater virtual world is in feet, standard DIS PDU is meters

              Inventor 1.0.1 and DIS libraries were NOT compatible due to
              programs hangups which are triggered by mallocs in the
              DIS libraries conflicting with the Inventor window.
              Removing DIS libraries and just putting malloc's in the
              Inventor screen redraw callback function caused identical
              program hangups. No fix was found. Upgrading to OpenInventor
              under Irix 5.2 eliminated this problem completely.

Future work:  Automated camera control

              .iv file load via WWW URLs

              optimization

*/
////////////////////////////////////
#include "../dynamics/AUVglobals.H"
#include <iostream.h>
```

```

#include <iomanip.h> // must follow iostream.h
#include <string.h>
#include <math.h>
#include <time.h>
#include <getopt.h>
#include <stdlib.h>
#include <netdb.h>
#include <netinet/in.h>
#include <sys/types.h>

////////////////////////////////////

// DIS includes. See Makefile for other DIS #include files; they must match.
#include "../DIS.mcast/h/disdefs.h"
#include "../DIS.mcast/h/appearance.h"

// Old DIS include statements follow, disregard...

// #include "/n/dude/work/brutzman/DIS.mcast/h/disdefs.h"
// #include "/n/dude/work/brutzman/DIS.mcast/h/appearance.h"

// John Locke's broadcast version
// #include "/n/gravy1/work/simnet/DIS-2.0/h/disdefs.h"
// #include "/n/gravy1/work/simnet/DIS-2.0/h/appearance.h"

// Macedonia/Zeswitz versions
#include "/n/elsie/work3/macedoni/net/mcast/network/h/disdefs.h"
#include "/n/elsie/work3/macedoni/net/mcast/network/h/appearance.h"

// #include "/n/elsie/work3/macedoni/net/mcast/network.round/h/disdefs.h"
// #include "/n/elsie/work3/macedoni/net/mcast/network.round/h/appearance.h"

extern "C" { printPDU (char *); }; // function prototype provided for
// compatibility, missing from DIS library

////////////////////////////////////

#include <X11/Intrinsic.h>
#include <Xm/Xm.h>
#include <Xm/CascadeBG.h>
#include <Xm/Form.h>
#include <Xm/RowColumn.h>
#include <Xm/PushButton.h>
#include <Xm/PushButtonBG.h>
#include <Xm/Separator.h>
#include <Xm/SeparatorG.h>
#include <Xm/ToggleButton.h>
#include <Xm/ToggleButtonBG.h>

#include <Inventor/So.h>
#include <Inventor/SoDB.h>
#include <Inventor/Xt/SoXt.h>
#include <Inventor/Xt/SoXtPrintDialog.h> // see SoOffscreenRender
#include <Inventor/Xt/SoXtRenderArea.h>
#include <Inventor/Xt/viewers/SoXtExaminerViewer.h>

#include <Inventor/sensors/SoTimerSensor.h>

#include <Inventor/actions/SoCallbackAction.h>
#include <Inventor/actions/SoWriteAction.h>

#include <Inventor/engines/SoCalculator.h>
#include <Inventor/engines/SoElapsedTime.h>
#include <Inventor/engines/SoTimeCounter.h>

#include <Inventor/nodes/SoComplexity.h>

```

```

#include <Inventor/nodes/SoCone.h>
#include <Inventor/nodes/SoCoordinate3.h>
#include <Inventor/nodes/SoCube.h>
#include <Inventor/nodes/SoCylinder.h>
#include <Inventor/nodes/SoDirectionalLight.h>
#include <Inventor/nodes/SoDrawStyle.h>
#include <Inventor/nodes/SoFaceSet.h>
#include <Inventor/nodes/SoGroup.h>
#include <Inventor/nodes/SoMaterial.h>
#include <Inventor/nodes/SoNurbsSurface.h>
#include <Inventor/nodes/SoPerspectiveCamera.h>
#include <Inventor/nodes/SoPickStyle.h>
#include <Inventor/nodes/SoRotationXYZ.h>
#include <Inventor/nodes/SoScale.h>
#include <Inventor/nodes/SoSelection.h>
#include <Inventor/nodes/SoSeparator.h>
#include <Inventor/nodes/SoSphere.h>
#include <Inventor/nodes/SoSwitch.h>
#include <Inventor/nodes/SoTransform.h>
#include <Inventor/nodes/SoTransformSeparator.h>
#include <Inventor/nodes/SoTranslation.h>
#include <Inventor/nodes/SoTriangleStripSet.h> // order matters here
#include <Inventor/nodes/SoUnits.h>

// leftovers from conversion 1.0.1 => OpenInventor

// #include <Inventor/Xt/SoXtColorEditor.h> // not found!

// #include <Inventor/nodes/SoBase.h>
// #include <Inventor/nodes/SoCallbackList.h>
// #include <Inventor/nodes/SoInteraction.h>
// #include <Inventor/Xt/SoXtFlyViewer.h>
// #include <Inventor/Xt/SoXtPlaneViewer.h>
// #include <Inventor/Xt/SoXtWalkViewer.h>

////////////////////////////////////
// function prototypes

static int  DIS_net_open   ();

static void DIS_net_close ();

static void DIS_Redraw_Callback ( void      * unused_data,
                                   SoSensor * unused_calling_sensor );

////////////////////////////////////

#define PI      3.1415926535897932

#define METERS_PER_FT  0.3048
#define FT_PER_METERS  3.2808

// utility function prototypes

double  sign      (double x);

double  degrees   (double x); // radians input

double  radians   (double x); // degrees input

double  arcclamp  (double x);

double  dnormalize (double angle_radians); // returns 0..2PI

int     inormalize (double angle_radians) // returns 0..359
        (return (int) (degrees (angle_radians) + 0.5) % 360;)}

```

```

SoSeparator * readFile(const char *filename); // Inventor Mentor p. 284

void    initialize_globals ();

void    parse_command_line_flags (int argc, char ** argv);

// global data (referenced in callback routines, thus defined here)

SoSeparator      * root;
SoTransform      * AUV_position_node;

// initializers needed to avoid startup segmentation fault

SoRotationXYZ    * rotate_AUV_z = new SoRotationXYZ;
SoRotationXYZ    * rotate_AUV_y = new SoRotationXYZ;
SoRotationXYZ    * rotate_AUV_x = new SoRotationXYZ;

SoRotationXYZ    * rotate_AUV_bow_rudders = new SoRotationXYZ;
SoRotationXYZ    * rotate_AUV_stern_rudders = new SoRotationXYZ;
SoRotationXYZ    * rotate_AUV_bow_planes = new SoRotationXYZ;
SoRotationXYZ    * rotate_AUV_stern_planes = new SoRotationXYZ;

SoCone           * thrusterWakeFV      = new SoCone;
SoCone           * thrusterWakeAV      = new SoCone;
SoCone           * thrusterWakeFH      = new SoCone;
SoCone           * thrusterWakeAH      = new SoCone;
SoCone           * conePropellerWakeStbd = new SoCone;
SoCone           * conePropellerWakePort = new SoCone;

SoSwitch         * whichWakeFV         = new SoSwitch;
SoSwitch         * whichWakeAV         = new SoSwitch;
SoSwitch         * whichWakeFH         = new SoSwitch;
SoSwitch         * whichWakeAH         = new SoSwitch;

SoTransform      * topsideBow           = new SoTransform;
SoTransform      * topsideStern         = new SoTransform;
SoTransform      * bottomsideBow        = new SoTransform;
SoTransform      * bottomsideStern      = new SoTransform;
SoTransform      * leftsideBow          = new SoTransform;
SoTransform      * leftsideStern        = new SoTransform;
SoTransform      * rightsideBow         = new SoTransform;
SoTransform      * rightsideStern       = new SoTransform;

SoTransform      * xfConeSonarST1000    = new SoTransform;
SoCone           * coneSonarST1000     = new SoCone;

SoMaterial * silver = new SoMaterial;
SoMaterial * gold   = new SoMaterial;
SoMaterial * brass  = new SoMaterial;
SoMaterial * chrome = new SoMaterial;
SoMaterial * npsblue = new SoMaterial;
SoMaterial * seagreen = new SoMaterial;
SoMaterial * darkgreen = new SoMaterial;
SoMaterial * sonar_red = new SoMaterial;

#define CAMERA_FREE      0
#define CAMERA_TO_AUV    1
#define CAMERA_FROM_AUV 2

static int whichCamera      = CAMERA_FREE; // default camera
static int PRINTDIALOG     = TRUE;
static int BACKGROUNDCOLORDIALOG = FALSE;
static int AUTOCAMERACONTROL = FALSE;

```

```

static int TEXTURE                                = FALSE;

SoPerspectiveCamera * PerspectiveCameraFree      = new SoPerspectiveCamera;
SoPerspectiveCamera * PerspectiveCameraToAUV     = new SoPerspectiveCamera;
SoPerspectiveCamera * PerspectiveCameraFromAUV   = new SoPerspectiveCamera;

// SbVec3f cameraToAUVPosition;

SbVec3f      behindAUVPosition;
SbVec3f      aheadOfAUVPosition;
SbVec3f      priorAUVPosition;
SbVec3f      currentAUVPosition;

SbVec3f      priorCameraPosition;
SbVec3f      currentCameraPosition;
SbVec3f      priorCameraOffset;
SbVec3f      currentCameraOffset;

SbVec3f      orientationRotationAxis;
float        orientationRotationAngle;

SbVec3f      standardCameraOffset      = SbVec3f ( - 20.0, 0.0, 2.0);

float        standardCameraFocalDistance = 20.0;

SoSeparator * command_line_node;

static clock_t      time_stamp_of_current_PDU,
                    time_of_PDU_receipt,
                    current_clock,
                    delta_clock;

static double       delta_time;

static int          PDU_overdue;

static int          DIS_port_open;

char              port [ 6];
char              group [30];

static SoUnits      * unitsfeet;

static struct in_addr      inaddr;

static struct hostent      * hp;

/////////////////////////////////////////////////////////////////

/////////////////////////////////////////////////////////////////
// all NPS AUV dimensions here in inches

#define HULLBODYLENGTH      54.00
#define HULLBODYWIDTH      16.50
#define HULLBODYHEIGHT     10.0

#define SEAM                -27.00    // - HULLBODYLENGTH / 2.0
#define STERN               -43.50    // - HULLBODYLENGTH / 2.0 - 16.5
#define LEFT                8.25     // HULLBODYWIDTH / 2.0
#define RIGHT               -8.25    // - HULLBODYWIDTH / 2.0
#define TOP                 5.00     // HULLBODYHEIGHT / 2.0
#define BOTTOM              -5.00    // - HULLBODYHEIGHT / 2.0

#define DOMECONTROLPT       25.00     // nosecone NURBS surface cooordinates
#define DOMECONTROLPTHALF  20.00     // offsets to help define shape

```

```

#define TOPHALF          4.75
#define BOTTOMHALF       -4.75
#define LEFT_HALF       8.00
#define RIGHTHALF        -8.00
#define CENTER           0.00

#define FINLENGTH        6.00 // fins need to be tapered
#define FINWIDTH          0.75 // fin thickness 1" at bottom, 0.5" at top
#define FINHEIGHT         6.75

#define FINOFFSETFORWARD 24.0
#define FINOFFSETAFT     -33.0
#define FINOFFSETLEFT    12.10 // (HULLBODYWIDTH / 2) + (FINHEIGHT / 2) + .5"
#define FINOFFSETRIGHT   -12.10
#define FINOFFSETUP       8.875 // (HULLBODYHEIGHT / 2) + (FINHEIGHT / 2) + .5"
#define FINOFFSETDOWN    -8.875

#define THRUSTERID        3.0
#define THRUSTEROD        3.5
#define THRUSTERFORWARDV 13.0 // forward SEAM - 14
#define THRUSTERAFTV      -21.0 // SEAM + 6
#define THRUSTERFORWARDH 19.0 // forward SEAM - 8
#define THRUSTERAFTH      -26.0 // SEAM + 1

#define SHAFTOFFSETLEFT   3.75
#define SHAFTOFFSETRIGHT -3.75

// reverify these dimensions after rebuild
#define CARDCAGELEFT      4.00
#define CARDCAGERIGHT     -4.00
#define CARDCAGELENGTH    12.00
#define CARDCAGEWIDTH     7.00
#define CARDCAGEHEIGHT    8.00

// profiling sonar, 1 degree conical
// watch out feet -> inches in code

#define AUV_ST1000_x_offset 34.5 // forward SEAM + 7.5"
#define AUV_ST1000_y_offset -2.00 //
#define AUV_ST1000_z_offset 4.00 // bottom forward

// scanning sonar sector, 1 degree wide by 24 degree vertical
#define AUV_ST725_x_offset 31.5 // forward SEAM + 4.5"
#define AUV_ST725_y_offset -2.00 //
#define AUV_ST725_z_offset -4.00 // top aft

////////////////////////////////////
SoSeparator * makeAUV ()
{
    rotate_AUV_z->angle.setValue ( AUV_psi);
    rotate_AUV_z->axis.setValue (SoRotationXYZ::Z);

    rotate_AUV_y->angle.setValue (- AUV_theta);
    rotate_AUV_y->axis.setValue (SoRotationXYZ::Y);

    rotate_AUV_x->angle.setValue ( AUV_phi);
    rotate_AUV_x->axis.setValue (SoRotationXYZ::X);

    SoDrawStyle *wires;
    wires = new SoDrawStyle;
    wires->style = SoDrawStyle::LINES;

    //////////////////////////////////////
    // NPS AUV hull body center is at [0.0 0.0 0.0],
    // volumetric center of buoyancy

    // fin transformations forward

```

```

SoTransform *xf1 = new SoTransform;
xf1->translation.setValue( FINOFFSETFORWARD, 0.0, FINOFFSETUP);
SoTransform *xf2 = new SoTransform;
xf2->translation.setValue( 0.0, 0.0, FINOFFSETDOWN - FINOFFSETUP);

SoTransform *xf3 = new SoTransform;
xf3->translation.setValue( FINOFFSETFORWARD, FINOFFSETLEFT, 0.0);
SoTransform *xf4 = new SoTransform;
xf4->translation.setValue( 0.0, FINOFFSETRIGHT - FINOFFSETLEFT, 0.0);

// fin transformations aft

SoTransform *xf5 = new SoTransform;
xf5->translation.setValue( FINOFFSETAFT, 0.0, FINOFFSETUP);
SoTransform *xf6 = new SoTransform;
xf6->translation.setValue( 0.0 , 0.0, FINOFFSETDOWN - FINOFFSETUP);

SoTransform *xf7 = new SoTransform;
xf7->translation.setValue( FINOFFSETAFT, FINOFFSETLEFT, 0.0);
SoTransform *xf8 = new SoTransform;
xf8->translation.setValue( 0.0, FINOFFSETRIGHT - FINOFFSETLEFT, 0.0);

// 90 degree increment rotations - get #define'd PI values

SoRotationXYZ *ro90x = new SoRotationXYZ;
ro90x->angle.setValue (3.141592653 / 2.0);
ro90x-> axis.setValue (SoRotationXYZ::X);

SoRotationXYZ *ro90y = new SoRotationXYZ;
ro90y->angle.setValue (3.141592653 / 2.0);
ro90y-> axis.setValue (SoRotationXYZ::Y);

SoRotationXYZ *ro90z = new SoRotationXYZ;
ro90z->angle.setValue (3.141592653 / 2.0);
ro90z-> axis.setValue (SoRotationXYZ::Z);

SoRotationXYZ *ro180x = new SoRotationXYZ;
ro180x->angle.setValue (3.141592653);
ro180x-> axis.setValue (SoRotationXYZ::X);

SoRotationXYZ *ro180y = new SoRotationXYZ;
ro180y->angle.setValue (3.141592653);
ro180y-> axis.setValue (SoRotationXYZ::Y);

SoRotationXYZ *ro180z = new SoRotationXYZ;
ro180z->angle.setValue (3.141592653);
ro180z-> axis.setValue (SoRotationXYZ::Z);

SoRotationXYZ *ro270x = new SoRotationXYZ;
ro270x->angle.setValue (- 3.141592653 / 2.0);
ro270x-> axis.setValue (SoRotationXYZ::X);

SoRotationXYZ *ro270y = new SoRotationXYZ;
ro270y->angle.setValue (- 3.141592653 / 2.0);
ro270y-> axis.setValue (SoRotationXYZ::Y);

SoRotationXYZ *ro270z = new SoRotationXYZ;
ro270z->angle.setValue (- 3.141592653 / 2.0);
ro270z-> axis.setValue (SoRotationXYZ::Z);

// construct NPS AUV hull body
SoCube *hull = new SoCube;
hull->width = HULLBODYLENGTH;
hull->height = HULLBODYWIDTH;
hull->depth = HULLBODYHEIGHT;

// construct a control fin

```

```

SoCube *fin = new SoCube;
fin->width = FINLENGTH;
fin->height = FINWIDTH;
fin->depth = FINHEIGHT;

// construct fin pairs

rotate_AUV_bow_rudders = new SoRotationXYZ;
rotate_AUV_bow_rudders->axis.setValue (SoRotationXYZ::Z);
rotate_AUV_bow_rudders->angle.setValue ( 0.3 );

rotate_AUV_stern_rudders = new SoRotationXYZ;
rotate_AUV_stern_rudders->axis.setValue (SoRotationXYZ::Z);
rotate_AUV_stern_rudders->angle.setValue ( 0.6 );

rotate_AUV_bow_planes = new SoRotationXYZ;
rotate_AUV_bow_planes->axis.setValue (SoRotationXYZ::Z);
rotate_AUV_bow_planes->angle.setValue ( 0.9 );

rotate_AUV_stern_planes = new SoRotationXYZ;
rotate_AUV_stern_planes->axis.setValue (SoRotationXYZ::Z);
rotate_AUV_stern_planes->angle.setValue ( 1.2 );

// construct forward vertical fins (bow rudders)
SoSeparator *fvfins = new SoSeparator;
fvfins->addChild( xf1 );
fvfins->addChild( rotate_AUV_bow_rudders );
fvfins->addChild( fin );
fvfins->addChild( xf2 );
fvfins->addChild( ro180x ); // net rotation 180
fvfins->addChild( fin );

// construct aft vertical fins (stern rudders)
SoSeparator *avfins = new SoSeparator;
avfins->addChild( xf5 );
avfins->addChild( rotate_AUV_stern_rudders );
avfins->addChild( fin );
avfins->addChild( xf6 );
avfins->addChild( ro180x ); // net rotation 180
avfins->addChild( fin );

// construct forward horizontal fins (bow planes)
SoSeparator *fhfins = new SoSeparator;
fhfins->addChild( xf3 );
fhfins->addChild( ro90x ); // net rotation 90
fhfins->addChild( rotate_AUV_bow_planes );
fhfins->addChild( fin );
fhfins->addChild( ro270x );
fhfins->addChild( xf4 );
fhfins->addChild( ro270x ); // net rotation 270 (in case of fin asymmetry)

fhfins->addChild( fin );

// construct aft horizontal fins (stern planes)
SoSeparator *ahfins = new SoSeparator;
ahfins->addChild( xf7 );
ahfins->addChild( ro90x ); // net rotation 90
ahfins->addChild( rotate_AUV_stern_planes );
ahfins->addChild( fin );
ahfins->addChild( ro270x );
ahfins->addChild( xf8 );
ahfins->addChild( ro270x ); // net rotation 270 (in case of fin asymmetry)
ahfins->addChild( fin );

// construct cylinders to represent the thrusters
SoTransform *xf13 = new SoTransform;
xf13->translation.setValue(THRUSTERFORWARDV, 0.0, 0.0);

```

```

SoTransform *xf14 = new SoTransform;
xf14->translation.setValue(THRUSTERAFTV, 0.0, 0.0);
SoTransform *xf15 = new SoTransform;
xf15->translation.setValue(THRUSTERFORWARDH, 0.0, 0.0);
SoTransform *xf16 = new SoTransform;
xf16->translation.setValue(THRUSTERAFTH, 0.0, 0.0);

SoCylinder * tubeV = new SoCylinder;
tubeV->radius = THRUSTERID;
tubeV->height = HULLBODYHEIGHT + 0.2;
SoCylinder * tubeH = new SoCylinder;
tubeH->radius = THRUSTERID;
tubeH->height = HULLBODYWIDTH + 0.2;

SoComplexity * wakeComplexity = new SoComplexity;
wakeComplexity->value = 0.2;

// still inches
topsideBow-> translation.setValue( 0, TOPHALF + AUV_bow_vertical, 0);
bottomsideBow-> translation.setValue( 0, BOTTOMHALF + AUV_bow_vertical, 0);
bottomsideBow-> rotation.setValue(SbVec3f ( 0.0, 1.0, 0.0 ), M_PI );

topsideStern-> translation.setValue( 0, TOPHALF + AUV_stern_vertical, 0);
bottomsideStern-> translation.setValue( 0, BOTTOMHALF + AUV_stern_vertical, 0);
bottomsideStern-> rotation.setValue(SbVec3f ( 0.0, 1.0, 0.0 ), M_PI );

leftsideBow-> translation.setValue( 0, LEFT_HALF + AUV_bow_lateral, 0);
leftsideBow-> rotation.setValue(SbVec3f ( 0.0, 1.0, 0.0 ), M_PI );
rightsideBow-> translation.setValue( 0, RIGHTHALF + AUV_bow_lateral, 0);

leftsideStern-> translation.setValue( 0, LEFT_HALF + AUV_stern_lateral, 0);
leftsideStern-> rotation.setValue(SbVec3f ( 0.0, 1.0, 0.0 ), M_PI );
rightsideStern-> translation.setValue( 0, RIGHTHALF + AUV_stern_lateral, 0);

thrusterWakeFV = new SoCone; // global for callbacks
thrusterWakeFV->height = AUV_bow_vertical * 2.0;
thrusterWakeFV->bottomRadius = AUV_bow_vertical / 4.0;
thrusterWakeFV->parts = SoCone::SIDES;

whichWakeFV = new SoSwitch;
whichWakeFV->addChild( topsideBow );
whichWakeFV->addChild( bottomsideBow );
whichWakeFV->whichChild = 0; // default topsideBow

SoSeparator * thrusterFV = new SoSeparator;
thrusterFV->addChild( xf13 );
thrusterFV->addChild( ro90x );
thrusterFV->addChild( tubeV );
thrusterFV->addChild( wires );
thrusterFV->addChild( wakeComplexity );
thrusterFV->addChild( seagreen );
thrusterFV->addChild( whichWakeFV );
thrusterFV->addChild( thrusterWakeFV );

thrusterWakeAV = new SoCone; // global for callbacks
thrusterWakeAV->height = AUV_stern_vertical * 2.0;
thrusterWakeAV->bottomRadius = AUV_stern_vertical / 4.0;
thrusterWakeAV->parts = SoCone::SIDES;

whichWakeAV = new SoSwitch;
whichWakeAV->addChild( topsideStern );
whichWakeAV->addChild( bottomsideStern );
whichWakeAV->whichChild = 0; // default topsideStern

SoSeparator * thrusterAV = new SoSeparator;
thrusterAV->addChild( xf14 );
thrusterAV->addChild( ro90x );

```

```

thrusterAV->addChild( tubeV );
thrusterAV->addChild( wires );
thrusterAV->addChild( wakeComplexity );
thrusterAV->addChild( seagreen );
thrusterAV->addChild( whichWakeAV );
thrusterAV->addChild( thrusterWakeAV );

thrusterWakeFH = new SoCone; // global for callbacks
thrusterWakeFH->height      = AUV_bow_lateral * 2.0;
thrusterWakeFH->bottomRadius = AUV_bow_lateral / 4.0;
thrusterWakeFH->parts       = SoCone::SIDES;

whichWakeFH = new SoSwitch;
whichWakeFH->addChild( leftsideBow);
whichWakeFH->addChild( rightsideBow);
whichWakeFH->whichChild = 0; // default leftsideBow

SoSeparator * thrusterFH = new SoSeparator;
thrusterFH->addChild( xf15 );
thrusterFH->addChild( ro90y );
thrusterFH->addChild( tubeH );
thrusterFH->addChild( ro180z );
thrusterFH->addChild( wires );
thrusterFH->addChild( wakeComplexity );
thrusterFH->addChild( seagreen );
thrusterFH->addChild( whichWakeFH );
thrusterFH->addChild( thrusterWakeFH );

thrusterWakeAH = new SoCone; // global for callbacks
thrusterWakeAH->height      = AUV_stern_lateral * 2.0;
thrusterWakeAH->bottomRadius = AUV_stern_lateral / 4.0;
thrusterWakeAH->parts       = SoCone::SIDES;

whichWakeAH = new SoSwitch;
whichWakeAH->addChild( leftsideStern);
whichWakeAH->addChild( rightsideStern);
whichWakeAH->whichChild = 0; // default leftsideStern

SoSeparator * thrusterAH = new SoSeparator;
thrusterAH->addChild( xf16 );
thrusterAH->addChild( ro90y );
thrusterAH->addChild( tubeH );
thrusterAH->addChild( ro180z );
thrusterAH->addChild( wires );
thrusterAH->addChild( wakeComplexity );
thrusterAH->addChild( seagreen );
thrusterAH->addChild( whichWakeAH );
thrusterAH->addChild( thrusterWakeAH );

// construct internal CARDCAGES left and right

SoCube *cardcageleftbox = new SoCube;
cardcageleftbox->width  = CARDCAGELENGTH;
cardcageleftbox->height = CARDCAGEWIDTH;
cardcageleftbox->depth  = CARDCAGEHEIGHT;

SoTransform *xfcardcageleft = new SoTransform;
xfcardcageleft->translation.setValue( 0.0, CARDCAGELEFT, 0.0 );

SoSeparator *cardcageleft = new SoSeparator;
cardcageleft->addChild( xfcardcageleft );
cardcageleft->addChild( cardcageleftbox );

SoCube *cardcagerightbox = new SoCube;
cardcagerightbox->width  = CARDCAGELENGTH;
cardcagerightbox->height = CARDCAGEWIDTH;
cardcagerightbox->depth  = CARDCAGEHEIGHT;

```

```

SoTransform *xfcardcageright = new SoTransform;
xfcardcageright->translation.setValue( 0.0, CARDCAGERIGHT, 0.0 );

SoSeparator *cardcageright = new SoSeparator;
cardcageright->addChild( xfcardcageright );
cardcageright->addChild( cardcagerightbox );

```

```

////////////////////////////////////
// construct main body out of parts
SoGroup *body = new SoGroup;

body->addChild( gold );
body->addChild( fvfins );
body->addChild( avfins );
body->addChild( fhfins );
body->addChild( ahfins );

body->addChild( npsblue );
body->addChild( hull );

body->addChild( silver );
body->addChild( thrusterFV );
body->addChild( thrusterAV );
body->addChild( thrusterFH );
body->addChild( thrusterAH );
body->addChild( cardcageleft );
body->addChild( cardcageright );

```

```

////////////////////////////////////
// construct nosecone using a NURBS surface

```

```

static float pts [25][3] =
{
    { - SEAM,                LEFT,      TOP      },
    { - SEAM,                LEFT_HALF, TOP      },
    { - SEAM,                CENTER,    TOP      },
    { - SEAM,                RIGHTHALF, TOP      },
    { - SEAM,                RIGHT,     TOP      },

    { - SEAM,                LEFT,      TOPHALF   },
    { - SEAM + DOMECONTROLPTHALF, LEFT_HALF, TOPHALF },
    { - SEAM + DOMECONTROLPTHALF, CENTER,  TOPHALF },
    { - SEAM + DOMECONTROLPTHALF, RIGHTHALF, TOPHALF },
    { - SEAM,                RIGHT,     TOPHALF   },

    { - SEAM,                LEFT,      CENTER    },
    { - SEAM + DOMECONTROLPTHALF, LEFT_HALF, CENTER },
    { - SEAM + DOMECONTROLPT,  CENTER,    CENTER },
    { - SEAM + DOMECONTROLPTHALF, RIGHTHALF, CENTER },
    { - SEAM,                RIGHT,     CENTER    },

    { - SEAM,                LEFT,      BOTTOMHALF },
    { - SEAM + DOMECONTROLPTHALF, LEFT_HALF, BOTTOMHALF },
    { - SEAM + DOMECONTROLPTHALF, CENTER,  BOTTOMHALF },
    { - SEAM + DOMECONTROLPTHALF, RIGHTHALF, BOTTOMHALF },
    { - SEAM,                RIGHT,     BOTTOMHALF },

    { - SEAM,                LEFT,      BOTTOM    },
    { - SEAM,                LEFT_HALF, BOTTOM    },
    { - SEAM,                CENTER,    BOTTOM    },
    { - SEAM,                RIGHTHALF, BOTTOM    },
    { - SEAM,                RIGHT,     BOTTOM    },
};

static float knots [10] =

```

```

        { 0, 0, 0, 0, 0, 1, 1, 1, 1, 1 };

SoComplexity *noseconeComplexity = new SoComplexity;
noseconeComplexity->value = 0.7;

SoCoordinate3 *controlPts = new SoCoordinate3;
controlPts->point.setValues ( 0, 25, pts );

SoNurbsSurface *sonardome = new SoNurbsSurface;
sonardome->numUControlPoints.setValue ( 5 );
sonardome->numVControlPoints.setValue ( 5 );
sonardome->uKnotVector.setValues ( 0, 10, knots );
sonardome->vKnotVector.setValues ( 0, 10, knots );

SoSeparator *nosesection = new SoSeparator;
nosesection->addChild( npsblue );
nosesection->addChild( noseconeComplexity );
nosesection->addChild( controlPts );
nosesection->addChild( sonardome );

coneSonarST1000 = new SoCone; // global for callbacks
coneSonarST1000->height = fabs (AUV_ST1000_range);
coneSonarST1000->bottomRadius = fabs (AUV_ST1000_range) / 60.0; // 1 degree
coneSonarST1000->parts = SoCone::SIDES;

// drawn from center
xfConeSonarST1000->translation.setValue( 0.0,
// - (HULLBODYLENGTH / 2.0)
// - (AUV_ST1000_range/ 2.0), 4.0/12.0);

SoSeparator * sepSonar = new SoSeparator;
sepSonar->addChild( ro90z );
sepSonar->addChild( wires );
sepSonar->addChild( wakeComplexity );
sepSonar->addChild( sonar_red );
sepSonar->addChild( xfConeSonarST1000 );
sepSonar->addChild( coneSonarST1000 );

////////////////////////////////////
// Define tail section

// ensure polygons are defined in clockwise fashion!

// Two triangles using SoTriangleStripSet:
static long numbertrianglevertices [2] = {3, 3};

static float afttrianglevertices [6][3] =
{
    {STERN, LEFT, 0.0}, {SEAM, LEFT, TOP}, {SEAM, LEFT, BOTTOM},
    {STERN, RIGHT, 0.0}, {SEAM, RIGHT, BOTTOM}, {SEAM, RIGHT, TOP},
};

// Define coordinates for triangular vertices & SoTriangleStripSet
SoCoordinate3 *tailcoord1 = new SoCoordinate3;
tailcoord1->point.setValues (0, 6, afttrianglevertices);

SoTriangleStripSet *tailtrianglestripset = new SoTriangleStripSet;
tailtrianglestripset->numVertices.setValues
    (0, 2, numbertrianglevertices);

// Two rectangles using FaceSet:
static long numberquadvertices [2] = {4, 4}; // ref. p. 5-6

static float aftquadvertices [8][3] =
{
    {STERN, LEFT, 0.0}, {STERN, RIGHT, 0.0}, {SEAM, RIGHT, TOP},
    {SEAM, LEFT, TOP},

```

```

    (STERN, RIGHT, 0.0), (STERN, LEFT, 0.0), (SEAM, LEFT, BOTTOM),
    (SEAM, RIGHT, BOTTOM),
};

// Define coordinates for quad vertices & SoFaceSet
SoCoordinate3 *tailcoord2 = new SoCoordinate3;
tailcoord2->point.setValues (0, 8, aftquadvertices);

SoFaceSet *tailquadset = new SoFaceSet;
tailquadset->numVertices.setValues (0, 2, numberquadvertices);

// Two cylinders currently represent the propellers - improve this!
// a much fancier individual prop model is possible here; also add complexity
SoCylinder *prop = new SoCylinder;
prop->radius = 2.00;
prop->height = 1.00;

// Two cylinders to represent the shafts
SoCylinder *shaft = new SoCylinder;
shaft->radius = 0.50;
shaft->height = 4.00;

SoTransform *xf18 = new SoTransform; // shafts relative to props
// note: rotated 90z
xf18->translation.setValue(0.0, -2.0, 0.0);

SoTransform *xf11 = new SoTransform; // left prop
xf11->translation.setValue(STERN - 2.0, SHAFTOFFSETLEFT, 0.0);

// compose shaft with prop
SoSeparator *leftprop = new SoSeparator;
leftprop->addChild( xf11 );
leftprop->addChild( ro90z );
leftprop->addChild( prop );
leftprop->addChild( xf18 );
leftprop->addChild( shaft );

SoTransform *xfPropellerWakePort = new SoTransform;
xfPropellerWakePort->translation.setValue( 0.0, 15.0, 0.0 );
SoSeparator * separatorPropellerWakePort = new SoSeparator;
separatorPropellerWakePort->addChild( xfPropellerWakePort );
separatorPropellerWakePort->addChild( ro180x );
separatorPropellerWakePort->addChild( wires );
separatorPropellerWakePort->addChild( wakeComplexity );
separatorPropellerWakePort->addChild( seagreen );
conePropellerWakePort = new SoCone; // global for callbacks
conePropellerWakePort->height = AUV_port_rpm / 700.0 * 24.0;
conePropellerWakePort->bottomRadius = fabs (AUV_port_rpm) / 700.0 * 6.0;
conePropellerWakePort->parts = SoCone::SIDES;
separatorPropellerWakePort->addChild( conePropellerWakePort );
leftprop->addChild( separatorPropellerWakePort );

SoTransform *xf12 = new SoTransform; // right props
xf12->translation.setValue(STERN - 2.0, SHAFTOFFSETRIGHT, 0.0);

SoSeparator *rightprop = new SoSeparator;
rightprop->addChild( xf12 );
rightprop->addChild( ro90z );
rightprop->addChild( prop );
rightprop->addChild( xf18 );
rightprop->addChild( shaft );

SoTransform *xfPropellerWakeStbd = new SoTransform;
xfPropellerWakeStbd->translation.setValue( 0.0, 15.0, 0.0 );
SoSeparator * separatorPropellerWakeStbd = new SoSeparator;
separatorPropellerWakeStbd->addChild( xfPropellerWakeStbd );
separatorPropellerWakeStbd->addChild( ro180x );

```

```

separatorPropellerWakeStbd->addChild( wires );
separatorPropellerWakeStbd->addChild( wakeComplexity );
separatorPropellerWakeStbd->addChild( seagreen );
conePropellerWakeStbd = new SoCone; // global for callbacks
conePropellerWakeStbd->height = AUV_port_rpm / 700.0 * 24.0;
conePropellerWakeStbd->bottomRadius = fabs (AUV_port_rpm) / 700.0 * 6.0;
conePropellerWakeStbd->parts = SoCone::SIDES;
separatorPropellerWakeStbd->addChild( conePropellerWakeStbd );
rightprop->addChild( separatorPropellerWakeStbd );

```

```

// construct stern box support beneath aft vertical fins
SoCube *sternfinsupportcube = new SoCube;
sternfinsupportcube->width = FINLENGTH + 1.5;
sternfinsupportcube->height = 5.0;
sternfinsupportcube->depth = HULLBODYHEIGHT - 0.5;

```

```

SoTransform *xf17 = new SoTransform;
xf17->translation.setValue(FINOFFSETAFT, 0.0, 0.0);

```

```

SoSeparator *sternfinsupport = new SoSeparator;
sternfinsupport->addChild( xf17 );
sternfinsupport->addChild( sternfinsupportcube );

```

```

SoSeparator *tailsection = new SoSeparator;
tailsection->addChild( npsblue );
tailsection->addChild( tailcoord1 );
tailsection->addChild( tailtriangle );
tailsection->addChild( tailcoord2 );
tailsection->addChild( tailquad );
tailsection->addChild( sternfinsupport );
tailsection->addChild( brass );
tailsection->addChild( leftprop );
tailsection->addChild( rightprop );

```

```

////////////////////////////////////
// robot is just units & body & nosesection & tailsection & extra stuff

```

```

SoSeparator * robot = new SoSeparator;

```

```

robot->addChild( unitsfeet );

```

```

// robot root transform for overall vehicle orientation
AUV_position_node = new SoTransform;
AUV_position_node->translation.setValue(0.0, 0.0, 0.0);
robot->addChild( AUV_position_node );

```

```

rotate_AUV_z = new SoRotationXYZ;
rotate_AUV_z->angle.setValue ( - AUV_psi);
rotate_AUV_z->axis.setValue (SoRotationXYZ::Z);
robot->addChild( rotate_AUV_z );

```

```

rotate_AUV_y = new SoRotationXYZ;
rotate_AUV_y->angle.setValue ( - AUV_theta);
rotate_AUV_y->axis.setValue (SoRotationXYZ::Y);
robot->addChild( rotate_AUV_y );

```

```

rotate_AUV_x = new SoRotationXYZ;
rotate_AUV_x->angle.setValue ( AUV_phi);
rotate_AUV_x->axis.setValue (SoRotationXYZ::X);
robot->addChild( rotate_AUV_x );

```

```

robot->addChild( sepSonar ); // feet

```

```

SoUnits *unitsinches = new SoUnits;
unitsinches->units.setValue ( SoUnits::INCHES );
robot->addChild( unitsinches );

```

```

SoPickStyle * unpickablestylenode;
SoPickStyle * pickablestylenode;
unpickablestylenode = new SoPickStyle;
pickablestylenode = new SoPickStyle;
unpickablestylenode->style.setValue ( SoPickStyle::UNPICKABLE );
pickablestylenode->style.setValue ( SoPickStyle::BOUNDING_BOX );

// Make subsequent nodes unpickable so that AUV is treated as a whole
robot->addChild( unpickablestylenode );

robot->addChild( body );
robot->addChild( nosesection );
robot->addChild( tailsection );

SoTransform *xf19 = new SoTransform;
xf19->translation.setValue( 0.0, 0.0, - 2.0);
robot->addChild( xf19 );
robot->addChild( new SoPointLight );
cout << "new point light added under robot" << endl;

return robot;
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
double sign (double x)
{
    if      (x > 0.0) return  1.0;
    else if (x < 0.0) return -1.0;
    else      return  1.0;
}

//-----//
double degrees (double x)    // radians input
{
    return x * 180.0 / PI;
}

//-----//
double radians (double x)    // degrees input
{
    return x * PI / 180.0;
}

//-----//
double arcclamp (double x)
{
    if      (x > 1.0)
    {
        x = 1.0;
        cout << "viewer: arcclamp reduced " << x << " to 1.0" << endl;
    }
    else if (x < -1.0)
    {
        x = -1.0;
        cout << "viewer: arcclamp raised " << x << " to -1.0" << endl;
    }
    return x;
}

//-----//
double dnormalize (double angle_radians)

```

```

    double new_angle = angle_radians;

    while (new_angle > 2*PI) new_angle -= 2*PI;
    while (new_angle < 0.0 ) new_angle += 2*PI;
    return new_angle;
}
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//-----//

static int DIS_net_open () // Ref: macedonia include files
{
    // Multicast Defaults from
    // /n/elsie/work3/macedoni/net/mcast/network/utils/planes/planes.cc

    // ttl value does not matter since this viewing program only reads PDUs
    u_char ttl = 16; // multicast ttl=16 stays inside NPS

    int exercise_id = -1;
    int coordinate_system = 0; // 0 = flat world, 1 = round world
    char * utm_file = "";

    int result = net_open (port, group, ttl,
                          exercise_id, coordinate_system, utm_file);

    // int result = net_open (port, group, ttl); // old version

    if result == FALSE;
    {
        cout << "viewer: DIS_net_open () failed" << endl;
        DIS_port_open = FALSE;
    }
    else
    {
        DIS_port_open = TRUE;

        // cout << "viewer: port = " << port << ", group = " << group
        // << ", ttl = " << ttl << endl;
        // cout << " exercise_id = " << exercise_id
        // << ", coordinate_system = " << coordinate_system
        // << ", utm_file = \" " << utm_file << "\" " << endl;

        return result;
    }
}
//-----//

static void DIS_Redraw_Callback ( void * unused_data,
                                SoSensor * unused_calling_sensor )
{
    double delta_x = 0.0;
    double delta_y = 0.0;
    double delta_z = 0.0;
    double delta_phi = 0.0;
    double delta_theta = 0.0;
    double delta_psi = 0.0;

    int number_of_PDUs;

    EntityID UUV_DIS_id;

    EntityType UUV_DIS_type;

    EntityStatePDU * UUV_DIS_pdu = NULL;

    char * local_PDU = NULL;

```

```

PDUType                                local_PDU_type;

static int rcvd = 0;

char      NPSAUV_Marking [8];
bzero     (NPSAUV_Marking, 8);
strncpy   (NPSAUV_Marking, "NPS AUV", 7); // 4 more free chars remain

if (delta_time <= 5.5)
    cout << "viewer: DIS_Redraw_Callback: PDU loop delta_time = "
        << delta_time << endl;

while (TRUE) // until break
{
    number_of_PDUs = net_read (& local_PDU, & local_PDU_type); // old version
    // number_of_PDUs = net_read (& local_PDU, & local_PDU_type, & inaddr);

    // cout << "viewer: net_read complete, number_of_PDUs available = "
    //      << number_of_PDUs << endl;

    if (number_of_PDUs == -1)
        cout << "viewer: Error on net_read, number_of_PDUs = -1" << endl;

    if (number_of_PDUs <= 0)
    {
        break; // no more PDUs, done for now
    }
    // rcvd ++;
    // cout << "PDU received, rcvd = " << rcvd << endl;
    // printPDU (local_PDU);

    UUV_DIS_pdu = (EntityStatePDU *) local_PDU;

    // ensure the PDU values are the right types
    if (local_PDU_type != EntityStatePDU_Type)
    {
        cout << "viewer: local_PDU_type != EntityStatePDU_Type, ignored..."
            << endl;

        // don't forget this or get a memory leak!
        // articulated parameters are also freed
        freePDU ((char *) UUV_DIS_pdu);
        cout << "viewer: freePDU ((char *) UUV_DIS_pdu) called for this PDU"
            << endl;

        continue; // not a break since other PDUs may be waiting
    }
    else if (strcmp ((char *) UUV_DIS_pdu->entity_marking.markings,
                    NPSAUV_Marking, 7) != 0)
    {
        cout << "viewer: non-NPS AUV Entity State PDU encountered, ignored..."
            << endl;
        // printPDU (local_PDU);
        freePDU ((char *) UUV_DIS_pdu);
        // don't forget this or get a memory leak!
        // articulated parameters are also freed
        cout << "viewer: freePDU ((char *) UUV_DIS_pdu) called for this PDU"
            << endl;

        continue; // not a break since other PDUs may be waiting
    }
    // cout << "PDU OK" << endl;

    // extract parameters of an entity state PDU (most are listed in pdu.h)
    //      this assumes there are no articulated parameters (add later) <<<

```

```

// DIS ID and Type
// UUV_DIS_id = UUV_DIS_pdu->entity_id;
// UUV_DIS_type = UUV_DIS_pdu->entity_type;

time_stamp_of_current_PDU = UUV_DIS_pdu->entity_state_header.time_stamp;
time_of_PDU_receipt = clock ();

PDU_overdue = FALSE;

// Posture
AUV_x = UUV_DIS_pdu->entity_location.x * FT_PER_METERS;
AUV_y = UUV_DIS_pdu->entity_location.y * FT_PER_METERS;
AUV_z = UUV_DIS_pdu->entity_location.z * FT_PER_METERS;
AUV_phi = radians (UUV_DIS_pdu->entity_orientation.phi);
AUV_theta = radians (UUV_DIS_pdu->entity_orientation.theta);
AUV_psi = radians (UUV_DIS_pdu->entity_orientation.psi);

cout << "viewer: DIS_net_read posture trace:" << endl;
cout << "[";
cout << UUV_DIS_pdu->entity_location.x << ", ";
cout << UUV_DIS_pdu->entity_location.y << ", ";
cout << UUV_DIS_pdu->entity_location.z << ", ";
cout << UUV_DIS_pdu->entity_orientation.phi << ", ";
cout << UUV_DIS_pdu->entity_orientation.theta << ", ";
cout << UUV_DIS_pdu->entity_orientation.psi << "]" << endl;

// Linear and angular velocities in body coordinates/meters by DIS standard
AUV_x_dot = UUV_DIS_pdu->entity_velocity.x * FT_PER_METERS;
AUV_y_dot = UUV_DIS_pdu->entity_velocity.y * FT_PER_METERS;
AUV_z_dot = UUV_DIS_pdu->entity_velocity.z * FT_PER_METERS;

AUV_phi_dot = radians(UUV_DIS_pdu->dead_reckon_params.angular_velocity[0]);
AUV_theta_dot = radians(UUV_DIS_pdu->dead_reckon_params.angular_velocity[1]);
AUV_psi_dot = radians(UUV_DIS_pdu->dead_reckon_params.angular_velocity[2]);

// cout << "viewer: World coordinate velocities: ";
// cout << "[";
// cout << UUV_DIS_pdu->entity_velocity.x << ", ";
// cout << UUV_DIS_pdu->entity_velocity.y << ", ";
// cout << UUV_DIS_pdu->entity_velocity.z << ", ";
// cout << UUV_DIS_pdu->dead_reckon_params.angular_velocity [0] << ", ";
// cout << UUV_DIS_pdu->dead_reckon_params.angular_velocity [1] << ", ";
// cout << UUV_DIS_pdu->dead_reckon_params.angular_velocity [2] << "]"
// << endl;
// cout << endl;

// Note that even though the accelerations are calculated in the superclass
// UUVBody, use of global state vector lets us construct a class hierarchy
// based on problem structure instead of the communications dependencies.
// This is proposed as a general DIS-compatible vehicle object hierarchy.

// Accelerations are not produced in world coordinates, thus zeroes expected
AUV_u_dot = UUV_DIS_pdu->dead_reckon_params.linear_accel [0] * FT_PER_METERS;
AUV_v_dot = UUV_DIS_pdu->dead_reckon_params.linear_accel [1] * FT_PER_METERS;
AUV_w_dot = UUV_DIS_pdu->dead_reckon_params.linear_accel [2] * FT_PER_METERS;

// cout << "viewer: World coordinate accelerations: ";
// cout << "[";
// cout << UUV_DIS_pdu->dead_reckon_params.linear_accel [0] << ", ";
// cout << UUV_DIS_pdu->dead_reckon_params.linear_accel [1] << ", ";
// cout << UUV_DIS_pdu->dead_reckon_params.linear_accel [2] << "]" << endl;

// what we look like
// UUV_DIS_pdu->entity_appearance;
// UUV_DIS_pdu->entity_marking.character_set;

```

```

// UUV_DIS_pdu->entity_marking.markings;

// project our movement
UUV_DIS_pdu->dead_reckon_params.algorithm = DRAlgo_DRM_FPW;

// cout << "viewer: DIS_net_read () successful" << endl;
// cout << flush;

// update overall AUV posture (both position & orientation)
AUV_position_node->translation.setValue ( AUV_x, - AUV_y, - AUV_z);
rotate_AUV_z-> angle.setValue ( - AUV_psi);
rotate_AUV_y-> angle.setValue ( - AUV_theta);
rotate_AUV_x-> angle.setValue ( AUV_phi);

ArticulatParamsNode * APNptr = UUV_DIS_pdu->articulat_params_head;

AUV_time = APNptr->articulat_params.parameter_value [0];
AUV_time += APNptr->articulat_params.parameter_value [1] / 10.0;
AUV_delta_rudder = APNptr->articulat_params.parameter_value [2];
AUV_delta_planes = APNptr->articulat_params.parameter_value [3];

// denormalize former shorts to be negative if necessary
if (AUV_delta_rudder >= 128.0) AUV_delta_rudder -= 256.0;
if (AUV_delta_planes >= 128.0) AUV_delta_planes -= 256.0;

AUV_port_rpm = APNptr->articulat_params.parameter_value [4];
if (AUV_port_rpm >= 128.0) AUV_port_rpm = AUV_port_rpm - 256.0;
AUV_port_rpm *= 10.0;
if (AUV_port_rpm >= 0.0)
    AUV_port_rpm += APNptr->articulat_params.parameter_value [5];
else AUV_port_rpm -= APNptr->articulat_params.parameter_value [5];

AUV_stbd_rpm = APNptr->articulat_params.parameter_value [6];
if (AUV_stbd_rpm >= 128.0) AUV_stbd_rpm = AUV_stbd_rpm - 256.0;
AUV_stbd_rpm *= 10.0;
if (AUV_stbd_rpm >= 0.0)
    AUV_stbd_rpm += APNptr->articulat_params.parameter_value [7];
else AUV_stbd_rpm -= APNptr->articulat_params.parameter_value [7];

// cout << "viewer: Articulation parameter 0:" << endl;
// cout << "AUV_time = " << AUV_time << endl;
// cout << "AUV_delta_rudder = " << AUV_delta_rudder << endl;
// cout << "AUV_delta_planes = " << AUV_delta_planes << endl;
// cout << "AUV_port_rpm = " << AUV_port_rpm << endl;
// cout << "AUV_stbd_rpm = " << AUV_stbd_rpm << endl;

APNptr = APNptr->next_articulat_params; // next articulated parameter

// thrusters
AUV_bow_vertical = APNptr->articulat_params.parameter_value [0];
AUV_stern_vertical = APNptr->articulat_params.parameter_value [1];
AUV_bow_lateral = APNptr->articulat_params.parameter_value [2];
AUV_stern_lateral = APNptr->articulat_params.parameter_value [3];

// denormalize former shorts to be negative if necessary
if (AUV_bow_vertical >= 128.0) AUV_bow_vertical -= 256.0;
if (AUV_stern_vertical >= 128.0) AUV_stern_vertical -= 256.0;
if (AUV_bow_lateral >= 128.0) AUV_bow_lateral -= 256.0;
if (AUV_stern_lateral >= 128.0) AUV_stern_lateral -= 256.0;

// convert thruster volts to force by signed squares & normalize adjust
AUV_bow_vertical = AUV_bow_vertical * fabs(AUV_bow_vertical) / 24.0;
AUV_stern_vertical = AUV_stern_vertical * fabs(AUV_stern_vertical) / 24.0;
AUV_bow_lateral = AUV_bow_lateral * fabs(AUV_bow_lateral) / 24.0;
AUV_stern_lateral = AUV_stern_lateral * fabs(AUV_stern_lateral) / 24.0;

// slots 4..7 as yet unused

```

```

// cout << "viewer: Articulation parameter 1: thrusters"
// << endl;
// cout << "AUV_bow_vertical = " << AUV_bow_vertical << endl;
// cout << "AUV_stern_vertical = " << AUV_stern_vertical << endl;
// cout << "AUV_bow_lateral = " << AUV_bow_lateral << endl;
// cout << "AUV_stern_lateral = " << AUV_stern_lateral << endl;

APNptr = APNptr->next_articulat_params; // next articulated parameter

AUV_ST1000_bearing = APNptr->articulat_params.parameter_value [0] * 10 +
APNptr->articulat_params.parameter_value [1];
AUV_ST1000_range = APNptr->articulat_params.parameter_value [2] / 4.0;
AUV_ST1000_strength = APNptr->articulat_params.parameter_value [3];
AUV_ST725_bearing = APNptr->articulat_params.parameter_value [4] * 10 +
APNptr->articulat_params.parameter_value [5];
AUV_ST725_range = APNptr->articulat_params.parameter_value [6] / 4.0;
AUV_ST725_strength = APNptr->articulat_params.parameter_value [7];

// cout << "viewer: Articulation parameter 2: sonar" << endl;
// cout << "AUV_ST1000_bearing = " << AUV_ST1000_bearing << endl;
// cout << "AUV_ST1000_range = " << AUV_ST1000_range << endl;
// cout << "AUV_ST1000_strength = " << AUV_ST1000_strength << endl;
// cout << "AUV_ST725_bearing = " << AUV_ST725_bearing << endl;
// cout << "AUV_ST725_range = " << AUV_ST725_range << endl;
// cout << "AUV_ST725_strength = " << AUV_ST725_strength << endl;

// Print hostname of PDU (revision in network.round version)
// hp = gethostbyaddr((char *) &inaddr, sizeof(struct in_addr), AF_INET);
// cout << "viewer: Host name: " << hp->h_name << endl;

// don't forget freePDU or get a memory leak!
// articulated parameters are also freed

freePDU (local_PDU);

// cout << "viewer: freePDU (local_PDU) called for this PDU" << endl;
} // end while infinite loop

// cout << "viewer: DIS net_read portion complete, now update scene graph."
// << endl;

current_clock = clock ();
delta_clock = current_clock - time_of_PDU_receipt;
delta_time = (double) delta_clock / CLOCKS_PER_SEC;

// cout << "viewer: current_clock = " << current_clock
// << ", time_stamp_of_current_PDU = " << time_stamp_of_current_PDU
// << ", time_of_PDU_receipt = " << time_of_PDU_receipt
// << ", PDU delta_time = " << delta_time << endl;

if ((delta_time >= 0.0) && (delta_time <= 5.0)) // update positions, postures
{
    delta_x = AUV_x_dot * delta_time;
    delta_y = AUV_y_dot * delta_time;
    delta_z = AUV_z_dot * delta_time;

    delta_phi = AUV_phi_dot * delta_time;
    delta_theta = AUV_theta_dot * delta_time;
    delta_psi = AUV_psi_dot * delta_time;

    // cout << "viewer: DeadReckon_Callback: "
    // << " PDU delta_time = " << delta_time << endl;
    // cout << " AUV_phi = " << degrees (AUV_phi) << endl;
    // << " AUV_phi_dot = " << degrees (AUV_phi_dot) << endl;
    // cout << " AUV_theta = " << degrees (AUV_theta) << endl;
    // << " AUV_theta_dot = " << degrees (AUV_theta_dot) << endl;

```

```

// cout << "   delta_x           = " << delta_x           << endl;
// cout << "   delta_y           = " << delta_y           << endl;
// cout << "   delta_z           = " << delta_z           << endl;
// cout << endl;

// save current position for next time the camera is repositioned
AUV_x_prior = AUV_x;
AUV_y_prior = AUV_y;
AUV_z_prior = AUV_z;

// graphics rendering problems: psi, rudders are opposite

// update overall AUV posture (both position & orientation)
AUV_position_node->translation.setValue ( AUV_x      + delta_x,
                                           - (AUV_y      + delta_y),
                                           - (AUV_z      + delta_z));
rotate_AUV_z->angle.setValue              ( - (AUV_psi   + delta_psi));
rotate_AUV_y->angle.setValue              ( - (AUV_theta + delta_theta));
rotate_AUV_x->angle.setValue              ( AUV_phi    + delta_phi);

// update AUV rudder & plane orientations

rotate_AUV_bow_rudders->angle.setValue   ( radians(AUV_delta_rudder));
rotate_AUV_stern_rudders->angle.setValue ( - radians(AUV_delta_rudder));
rotate_AUV_bow_planes->angle.setValue    ( - radians(AUV_delta_planes));
rotate_AUV_stern_planes->angle.setValue   ( radians(AUV_delta_planes));

// cout << "AUV_delta_rudder = " << AUV_delta_rudder
//      << ", radians (AUV_delta_rudder) = "
//      << radians (AUV_delta_rudder)
//      << endl;
// cout << "AUV_delta_planes= " << AUV_delta_planes
//      << ", radians (AUV_delta_planes) = "
//      << radians (AUV_delta_planes)
//      << endl;

if (fabs(AUV_stbd_rpm -
         (conePropellerWakeStbd->height.getValue() * 700.0/24.0)) > 10.0)
// ensure needed
{
    conePropellerWakeStbd->height          = AUV_stbd_rpm /700.0*24.0;
    conePropellerWakeStbd->bottomRadius = fabs (AUV_stbd_rpm) /700.0* 6.0;
}
if (fabs(AUV_port_rpm -
         (conePropellerWakePort->height.getValue() * 700.0 / 24.0)) > 10.0)
// ensure needed
{
    conePropellerWakePort->height          = AUV_port_rpm /700.0*24.0;
    conePropellerWakePort->bottomRadius = fabs (AUV_port_rpm) /700.0* 6.0;
}
if (fabs(AUV_bow_vertical-(thrusterWakeFV->height.getValue()/2.0)) > 1.0)
// ensure needed
{
    thrusterWakeFV->height          = - AUV_bow_vertical * 2.0;
    thrusterWakeFV->bottomRadius = AUV_bow_vertical / 4.0;
    if (AUV_bow_vertical < 0.0)
        // bottomsideBow, negative volts push up (negative direction)
        whichWakeFV->whichChild = 1;
        // topsideBow, positive volts push down (positive direction)
    else whichWakeFV->whichChild = 0;

    topsideBow-> translation.setValue(0, TOPHALF+AUV_bow_vertical,0);
    bottomsideBow->translation.setValue(0, BOTTOMHALF+AUV_bow_vertical,0);
}
if (fabs(AUV_stern_vertical-(thrusterWakeAV->height.getValue()/2.0))
    > 1.0)
// ensure needed

```

```

{
    thrusterWakeAV->height      = - AUV_stern_vertical * 2.0;
    thrusterWakeAV->bottomRadius = AUV_stern_vertical / 4.0;
    if (AUV_stern_vertical < 0.0)
        // bottomsidestern, negative volts push up (negative direction)
        whichWakeAV->whichChild = 1;
        // topsidestern, positive volts push down(positive direction)
    else whichWakeAV->whichChild = 0;

    topsidestern->translation.setValue(0, TOPHALF+AUV_stern_vertical,0);
    bottomsidestern->translation.setValue(0,BOTTOMHALF+AUV_stern_vertical,0);
}
if (fabs(AUV_bow_lateral-(thrusterWakeFH->height.getValue()/2.0)) > 1.0)
// ensure needed
{
    thrusterWakeFH->height      = - AUV_bow_lateral * 2.0;
    thrusterWakeFH->bottomRadius = AUV_bow_lateral / 4.0;
    if (AUV_bow_lateral < 0.0)
        // rightsideBow, negative volts push left (negative direction)
        whichWakeFH->whichChild = 1;
        // leftsideBow, positive volts push right (positive direction)
    else whichWakeFH->whichChild = 0;

    leftsideBow->translation.setValue ( 0, LEFT_HALF+AUV_bow_lateral, 0);
    rightsideBow->translation.setValue ( 0, RIGHTHALF+AUV_bow_lateral, 0);
}
if (fabs(AUV_stern_lateral-(thrusterWakeAH->height.getValue()/2.0))
    > 1.0)
// ensure needed
{
    thrusterWakeAH->height      = - AUV_stern_lateral * 2.0;
    thrusterWakeAH->bottomRadius = AUV_stern_lateral / 4.0;
    if (AUV_stern_lateral < 0.0)
        // rightsidestern, negative volts push left (negative direction)
        whichWakeAH->whichChild = 1;
        // leftsidestern, positive volts push right(positive direction)
    else whichWakeAH->whichChild = 0;

    leftsidestern->translation.setValue(0,LEFT_HALF+AUV_stern_lateral,0);
    rightsidestern->translation.setValue(0,RIGHTHALF+AUV_stern_lateral,0);
}
if (fabs(AUV_ST1000_range - coneSonarST1000->height.getValue()) > 0.0)
// ensure needed
{
    coneSonarST1000->height      = fabs (AUV_ST1000_range);
    coneSonarST1000->bottomRadius = fabs (AUV_ST1000_range) / 60.0;
                                // 1 degree
    xfcConeSonarST1000->translation.setValue ( 0.0,
                                                - (AUV_ST1000_range / 2.0),
                                                4.0 / 12.0 );
}
}
else if (PDU_overdue == FALSE) // update scene graph, reset vehicle position
{
    PDU_overdue = TRUE; // over 5 seconds elapsed since last PDU

    // restore latest valid AUV posture (both position & orientation)
    AUV_position_node->translation.setValue ( AUV_x,
                                              - AUV_y,
                                              - AUV_z);
    rotate_AUV_z->angle.setValue ( - AUV_psi);
    rotate_AUV_y->angle.setValue ( - AUV_theta);
    rotate_AUV_x->angle.setValue ( AUV_phi);

    // thrusters
    AUV_bow_vertical = 0.0;
    AUV_stern_vertical = 0.0;

```

```

AUV_bow_lateral      = 0.0;
AUV_stern_lateral    = 0.0;

thrusterWakeFV->height      = 0.0;
thrusterWakeFV->bottomRadius = 0.0;
thrusterWakeAV->height      = 0.0;
thrusterWakeAV->bottomRadius = 0.0;
thrusterWakeFH->height      = 0.0;
thrusterWakeFH->bottomRadius = 0.0;
thrusterWakeAH->height      = 0.0;
thrusterWakeAH->bottomRadius = 0.0;

AUV_ST1000_bearing = 0;
AUV_ST1000_range   = 0.0;
AUV_ST1000_strength = 0;
AUV_ST725_bearing  = 0;
AUV_ST725_range    = 0.0;
AUV_ST725_strength = 0;

coneSonarST1000->height      = fabs(AUV_ST1000_range);
coneSonarST1000->bottomRadius = fabs(AUV_ST1000_range)/60.0; // 1 degree.

AUV_port_rpm = 0.0;
AUV_stbd_rpm = 0.0;

conePropellerWakePort->height      = 0.0;
conePropellerWakePort->bottomRadius = 0.0;
conePropellerWakeStbd->height      = 0.0;
conePropellerWakeStbd->bottomRadius = 0.0;

cout << "viewer: DeadReckon_Callback: "
      << "PDU delta_time = " << delta_time << ", "
      << endl;
cout << "viewer position/posture reset to last received PDU." << endl;
cout << endl;
cout << flush;

// globals
priorAUVPosition = SVec3f (AUV_x_prior, AUV_y_prior, AUV_z_prior);
currentAUVPosition = SVec3f (AUV_x, AUV_y, AUV_z);
aheadOfAUVPosition = currentAUVPosition +
                      SVec3f (10.0*cos (AUV_psi), 10.0*sin(AUV_psi), 2.0);

switch ( whichCamera ) // reposition appropriate camera as needed
{
case CAMERA_FREE:
    priorCameraPosition = PerspectiveCameraFree->position.getValue ();
    priorCameraOffset   = priorCameraPosition - priorAUVPosition;
    currentCameraPosition = priorCameraPosition;
    PerspectiveCameraFree->orientation.getValue(orientationRotationAxis,
                                                  orientationRotationAngle);
    break;

case CAMERA_TO_AUV: // retain camera pos'n relative to new AUV position
    priorCameraPosition = PerspectiveCameraToAUV->position.getValue ();
    priorCameraOffset   = priorCameraPosition - priorAUVPosition;
// verify here
    currentCameraPosition =
        ( currentAUVPosition
          + standardCameraOffset );
    PerspectiveCameraToAUV->position.setValue
        ( currentAUVPosition
          + standardCameraOffset );
    PerspectiveCameraToAUV->pointAt
        (currentAUVPosition );
    PerspectiveCameraToAUV->focalDistance.setValue(standardCameraFocalDistance);
    PerspectiveCameraToAUV->orientation.getValue
        (orientationRotationAxis,
         orientationRotationAngle );
    break;

```

```

        case CAMERA_FROM_AUV: // retain camera position looking out from AUV pos.
            priorCameraPosition = PerspectiveCameraFromAUV->position.getValue ();
            priorCameraOffset   = priorCameraPosition - priorAUVPosition;
// verify here
            currentCameraPosition = ( currentAUVPosition );
            PerspectiveCameraFromAUV->position.setValue ( currentAUVPosition );
            PerspectiveCameraFromAUV->pointAt ( currentAUVPosition
                                                +standardCameraOffset );
            PerspectiveCameraFromAUV->focalDistance.setValue(standardCameraFocalDistance);
            PerspectiveCameraFromAUV->orientation.getValue (orientationRotationAxis,
                                                            orientationRotationAngle );
            break;

        } // end switch ( whichCamera )

// print out all camera parameters
cout << endl;
cout << "      AUV_position      = <" << (AUV_x)
      << ", " << (AUV_y)
      << ", " << (AUV_z) << ">" << endl;
cout << "delta_AUV_position    = <" << (AUV_x - AUV_x_prior)
      << ", " << (AUV_y - AUV_y_prior)
      << ", " << (AUV_z - AUV_z_prior) << ">" << endl;
cout << "delta_CameraPosition = "
      << "<" << (currentCameraPosition [0] - priorCameraPosition [0])
      << ", " << (currentCameraPosition [1] - priorCameraPosition [1])
      << ", " << (currentCameraPosition [2] - priorCameraPosition [2])
      << ">" << endl;
cout << "      priorCameraPosition = "
      << "<" << priorCameraPosition [0]
      << ", " << priorCameraPosition [1]
      << ", " << priorCameraPosition [2] << ">" << endl;
cout << "      priorCameraOffset  = "
      << "<" << priorCameraOffset [0]
      << ", " << priorCameraOffset [1]
      << ", " << priorCameraOffset [2] << ">" << endl;
cout << "      currentCameraPosition = "
      << "<" << currentCameraPosition [0]
      << ", " << currentCameraPosition [1]
      << ", " << currentCameraPosition [2] << ">" << endl;
cout << "      orientationRotation = "
      << "<" << orientationRotationAxis [0]
      << ", " << orientationRotationAxis [1]
      << ", " << orientationRotationAxis [2]
      << ", " << degrees (orientationRotationAngle) << ">" << endl;

// cout << "viewer:  end of DIS_Redraw_Callback ()" << endl;

return;
}
//-----//

// called on an exit condition via a call to atexit (DIS_net_close) in main
static void DIS_net_close ()
{
    cout << "viewer: DIS_net_close ();" << endl;
    net_close ();
    DIS_port_open = FALSE;
}
//-----//

////////////////////////////////////

```

```

//
// This is called by the Color Editor whenever the color
// has changed. The userData is set by main() in the call
// to SoXtColorEditor::addColorChangedCallback.
//
void
colorEditorCB( void *userData, const SbColor *rgbCallbackData )
{
    SoXtRenderArea *renderArea = (SoXtRenderArea *) userData;
    renderArea->setBackgroundColor( *rgbCallbackData );
}

/////////////////////////////////////////////////////////////////

SoSeparator * readFile(const char *filename) // Inventor Mentor p. 284
{
    // Open the input file
    SoInput mySceneInput;
    if (!mySceneInput.openFile(filename))
    {
        cout << "Cannot open file " << filename << endl;
        return NULL;
    }
    // Read the whole file into the database
    SoSeparator * myGraph = SoDB::readAll(&mySceneInput);
    if (myGraph == NULL)
    {
        cout << "Problem reading file " << filename << endl;
        return NULL;
    }
    mySceneInput.closeFile ();
    return myGraph;
}

/////////////////////////////////////////////////////////////////

void initialize_globals ()
{
    // multicast port & group
    strncpy (port, "3111", 4);
    strncpy (group, "224.2.121.93", 12);

    // 3111 is npsnet 'standard' port
    // #define DEFAULT_PORT = "3111";
    // #define DEFAULT_GROUP = "224.2.121.93";

    // initialize materials
    silver->ambientColor.setValue ( .2, .2, .2 );
    silver->diffuseColor.setValue ( .6, .6, .6 );
    silver->specularColor.setValue ( .5, .5, .5 );
    silver->shininess = .5;

    gold->ambientColor.setValue ( .4, .2, .0 );
    gold->diffuseColor.setValue ( .9, .5, .0 );
    gold->specularColor.setValue ( .7, .7, .0 );
    gold->shininess = .6;

    brass->ambientColor.setValue ( 0.329412, 0.223529, 0.027451 );
    brass->diffuseColor.setValue ( 0.780392, 0.568627, 0.113725 );
    brass->specularColor.setValue ( 0.992157, 0.941176, 0.807843 );
    brass->shininess = 0.21794872;

    chrome->ambientColor.setValue ( 0.25, 0.25, 0.25 );
    chrome->diffuseColor.setValue ( 0.4, 0.4, 0.4 );
    chrome->specularColor.setValue ( 0.774597, 0.774597, 0.774597 );
    chrome->shininess = 0.6;
}

```

```

npsblue-> ambientColor.setValue ( 0.0, 0.0, 1.0 );
npsblue-> diffuseColor.setValue ( 0.0, 0.0, 0.8 );
npsblue-> specularColor.setValue ( 0.0, 0.2, 1.0 );
npsblue-> shininess = 0.8;

seagreen-> ambientColor.setValue ( 0.0, 0.5, 0.0 );
seagreen-> diffuseColor.setValue ( 0.0, 0.5, 0.0 );
seagreen-> specularColor.setValue ( 0.0, 0.5, 0.0 );
seagreen-> shininess = 0.0;

darkgreen-> ambientColor.setValue ( 0.15, 0.20, 0.15 );
darkgreen-> diffuseColor.setValue ( 0.15, 0.20, 0.15 );
darkgreen-> specularColor.setValue ( 0.15, 0.20, 0.15 );
darkgreen-> shininess = 0.0;

sonar_red-> ambientColor.setValue ( 1.0, 0.0, 0.15 );
sonar_red-> diffuseColor.setValue ( 1.0, 0.0, 0.15 );
sonar_red-> specularColor.setValue ( 1.0, 0.0, 0.15 );
sonar_red-> shininess = 0.0;

return;
// end initialize_globals ()

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

void parse_command_line_flags (int argc, char ** argv)
    // command line arguments
{
    int index, i;

    // cout << "[parse_command_line_flags start: # arguments = " << argc << "]"
    // << endl;
    // cout << "{" << " ";
    // for (i = 0; i < argc; i++) cout << argv [i] << " ";
    // cout << "}" << endl;

    for (i = 1; i < argc; i++)
    {
        for (index = 0; index <= strlen (argv[i]); index++) // uppercase
            argv[i] [index] = toupper (argv[i] [index]);

        if ((strcmp (argv[i], "PORT") == 0) ||
            (strcmp (argv[i], "-PORT") == 0) ||
            (strcmp (argv[i], "P") == 0) ||
            (strcmp (argv[i], "-P") == 0))
        {
            if (i+1 >= argc)
                cout << "Insufficient parameters for PORT" << endl;
            else
            {
                cout << "[" << argv[i] << " " << argv[i+1] << "]" << endl;
                strcpy (port, argv[i+1]);
                i++;
            }
        }
        else if ((strcmp (argv[i], "GROUP") == 0) ||
            (strcmp (argv[i], "-GROUP") == 0) ||
            (strcmp (argv[i], "G") == 0) ||
            (strcmp (argv[i], "-G") == 0) ||
            (strcmp (argv[i], "ADDRESS") == 0) ||
            (strcmp (argv[i], "-ADDRESS") == 0) ||
            (strcmp (argv[i], "A") == 0) ||
            (strcmp (argv[i], "-A") == 0))
        {
            if (i+1 >= argc)
                cout << "Insufficient parameters for GROUP ADDRESS" << endl;

```

```

else
{
    cout << "[" << argv[i] << " " << argv[i+1] << "]" << endl;
    strcpy (group, argv[i+1]);
    i++;
    cout << "[" << argv[i] << " " << argv[i+1] << "]" << endl;
}
else if ((strcmp (argv[i], "PRINTDIALOG") == 0) ||
        (strcmp (argv[i], "-PRINTDIALOG") == 0))
{
    PRINTDIALOG = TRUE;
    cout << "[" << argv[i] << "]" << endl;
}
else if ((strcmp (argv[i], "TEXTURE") == 0) ||
        (strcmp (argv[i], "-TEXTURE") == 0) ||
        (strcmp (argv[i], "TEXTURE-ON") == 0) ||
        (strcmp (argv[i], "-TEXTURE-ON") == 0) ||
        (strcmp (argv[i], "T") == 0) ||
        (strcmp (argv[i], "-T") == 0))
{
    TEXTURE = TRUE;
    cout << "[" << argv[i] << "]" << endl;
}
else if ((strcmp (argv[i], "NOTEXTURE") == 0) ||
        (strcmp (argv[i], "-NOTEXTURE") == 0) ||
        (strcmp (argv[i], "TEXTURE-OFF") == 0) ||
        (strcmp (argv[i], "-TEXTURE-OFF") == 0))
{
    TEXTURE = FALSE;
    cout << "[" << argv[i] << "]" << endl;
}
else if ((strcmp (argv[i], "FILE") == 0) ||
        (strcmp (argv[i], "-FILE") == 0) ||
        (strcmp (argv[i], "F") == 0) ||
        (strcmp (argv[i], "-F") == 0))
{
    if (i+1 >= argc)
        cout << "Insufficient parameters for FILE filename.iv"
            << endl;
    else
    {
        cout << "[" << argv[i] << " " << argv[i+1] << "]" << endl;
        command_line_node = new SoSeparator;
        command_line_node = readFile (argv[i+1]);
        root-> addChild ( command_line_node );
        i++;
    }
}
else if ((strcmp (argv[i], "NOPRINTDIALOG") == 0) ||
        (strcmp (argv[i], "-NOPRINTDIALOG") == 0))
{
    PRINTDIALOG = FALSE;
    cout << "[" << argv[i] << "]" << endl;
}
else if ((strcmp (argv[i], "BACKGROUNDCOLORDIALOG") == 0) ||
        (strcmp (argv[i], "-BACKGROUNDCOLORDIALOG") == 0))
{
    BACKGROUNDCOLORDIALOG = TRUE;
    cout << "[" << argv[i] << "]" << endl;
}
else if ((strcmp (argv[i], "NOBACKGROUNDCOLORDIALOG") == 0) ||
        (strcmp (argv[i], "-NOBACKGROUNDCOLORDIALOG") == 0))
{
    BACKGROUNDCOLORDIALOG = FALSE;
    cout << "[" << argv[i] << "]" << endl;
}

```

```

        else cout << "Unrecognized command line parameter: '" << argv[i]
                << "', ignored." << endl;

    } // end for loop through command line parameters

    // cout << "[parse_command_line_flags complete]" << endl;

    return;

} // end parse_command_line_flags ()

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

main ( int argc, char ** argv )
{
    // Initialize Inventor and Xt - these steps MUST be first calls
    // in main, without exception, or a mystery crash results.
    Widget ViewerWindowWidget = SoXt::init(argv[0]);
    if ( ViewerWindowWidget == NULL )
    {
        cout << "viewer: ViewerWindowWidget == NULL on startup, exiting."
              << endl;
        exit( 1 );
    }
    cout << "viewer: ViewerWindowWidget added" << endl;

    initialize_globals ();

    parse_command_line_flags (argc, argv);

    // port and group can change by command line switches
    cout << "multicast port = " << port
          << ", address group = " << group << endl;

    cout << "creating the scene graph:" << endl;

    root = new SoSeparator;
    root->ref();
    cout << "root added" << endl;

    // correct for different coordinate system - not yet working
    // SoRotationXYZ * coordinateSystemFlip = new SoRotationXYZ;
    // coordinateSystemFlip->angle.setValue ( M_PI );
    // coordinateSystemFlip->axis.setValue ( SoRotationXYZ::X );
    // root->addChild( coordinateSystemFlip );

    SoRotationXYZ *ro0x = new SoRotationXYZ;
    ro0x->angle.setValue ( 0.0 );
    ro0x->axis.setValue (SoRotationXYZ::X);

    SoRotationXYZ *ro90x = new SoRotationXYZ;
    ro90x->angle.setValue (M_PI / 2.0);
    ro90x->axis.setValue (SoRotationXYZ::X);

    SoRotationXYZ *ro270x = new SoRotationXYZ;
    ro270x->angle.setValue (3.0 * M_PI / 2.0);
    ro270x->axis.setValue (SoRotationXYZ::X);

    PerspectiveCameraFree      = new SoPerspectiveCamera;
    PerspectiveCameraToAUV     = new SoPerspectiveCamera;
    PerspectiveCameraFromAUV   = new SoPerspectiveCamera;

    // can't put a group or separator above camera
    // cameras using pointAt are 90 degrees twisted askew
    // Create a camera SoSwitch node

```

```

SoSwitch * whichCameraSwitch = new SoSwitch;
root->addChild ( whichCameraSwitch );
whichCameraSwitch->addChild ( PerspectiveCameraFree );
whichCameraSwitch->addChild ( PerspectiveCameraToAUV );
whichCameraSwitch->addChild ( PerspectiveCameraFromAUV );
// default whichCamera defined at top
whichCameraSwitch->whichChild = whichCamera;

// Create a camera rotation correction SoSwitch node
SoSwitch * whichCameraCorrectionSwitch = new SoSwitch;
root->addChild ( whichCameraCorrectionSwitch );
whichCameraCorrectionSwitch->addChild ( ro0x );
whichCameraCorrectionSwitch->addChild ( ro270x );
whichCameraCorrectionSwitch->addChild ( ro270x );
whichCameraCorrectionSwitch->whichChild = whichCamera;

root->addChild( new SoPointLight );

SoTransform * xfLight2 = new SoTransform;
xfLight2->translation.setValue(0.0, 0.0, - 30.0);
root->addChild( xfLight2 );
root->addChild( new SoPointLight );
SoTransform * xfLight3 = new SoTransform;
xfLight3->translation.setValue(0.0, 0.0, 30.0);
root->addChild( xfLight3 );
cout << "2 point lights added " << endl;

SoXtRenderArea * myRenderArea = new SoXtRenderArea (ViewerWindowWidget);
SbViewportRegion myRegion (myRenderArea->getSize ());

currentAUVPosition = SbVec3f (AUV_x, AUV_y, AUV_z); // globals
aheadOfAUVPosition = currentAUVPosition +
    SbVec3f (10.0 * cos (AUV_psi), 10.0 * sin (AUV_psi), 0.0);
// global

// Free (unmodified) Camera
PerspectiveCameraFree->viewAll (root, myRegion, 1.0); // global
PerspectiveCameraFree->aspectRatio.setValue (SO_ASPECT_VIDEO);

// Camera that keeps AUV in center
PerspectiveCameraToAUV->viewAll (root, myRegion, 1.0); // global
PerspectiveCameraToAUV->aspectRatio.setValue (SO_ASPECT_VIDEO);
PerspectiveCameraToAUV->position.setValue
    ( currentAUVPosition + standardCameraOffset );
// PerspectiveCameraToAUV->orientation.setValue
    (SbRotation (1.0, 0.0, 0.0, M_PI / 2.0 ));
PerspectiveCameraToAUV->pointAt ( currentAUVPosition );

// Camera that looks out from AUV in center
PerspectiveCameraFromAUV->viewAll (root, myRegion, 1.0); // global
PerspectiveCameraFromAUV->aspectRatio.setValue (SO_ASPECT_VIDEO);
PerspectiveCameraFromAUV->position.setValue ( currentAUVPosition );
// PerspectiveCameraFromAUV->orientation.setValue
    (SbRotation (1.0, 0.0, 0.0, M_PI / 2.0 ));
PerspectiveCameraFromAUV->pointAt ( currentAUVPosition + standardCameraOffset );

unitsfeet = new SoUnits;
unitsfeet->units.setValue ( SoUnits::FEET );
root->addChild( unitsfeet );

SoPickStyle * unpickablestylenode;
SoPickStyle * pickablestylenode;
unpickablestylenode = new SoPickStyle;
pickablestylenode = new SoPickStyle;
unpickablestylenode->style.setValue ( SoPickStyle::UNPICKABLE );
pickablestylenode->style.setValue ( SoPickStyle::BOUNDING_BOX );

```



```

    // Testtank
    SoSeparator * sepTesttank = new SoSeparator;
    SoTransform * xfTesttank = new SoTransform;
    SoSeparator * Testtank = readFile ("Testtank.iv");
    xfTesttank->translation.setValue( 0.0, 0.0, -50.0);
    sepTesttank->addChild ( xfTesttank );
    sepTesttank->addChild( Testtank );
    root->addChild ( sepTesttank );

    // Torpedo Tube
    SoSeparator * sepTorpedoTube = new SoSeparator;
    SoTransform * xfTorpedoTube = new SoTransform;
    xfTorpedoTube->translation.setValue( 30.0, 20.0, -48.00 );
    SoCylinder * TorpedoTube = new SoCylinder;
    TorpedoTube->radius = 21.0 / 12.0; // 21" diameter
    TorpedoTube->height = 10.0; // 10' length
    TorpedoTube->parts = SoCylinder::SIDES; // let's drive through!
    sepTorpedoTube->addChild ( xfTorpedoTube );
    sepTorpedoTube->addChild( TorpedoTube );
    root->addChild ( brass );
    root->addChild ( sepTorpedoTube );

    SoSeparator * AUV_node = makeAUV();

    root->addChild ( AUV_node ); // AUV object creation routine above

    // WriteAction writes scene graph to file
    FILE * auv_iv_fp = fopen ("auv.iv", "w");
    SoWriteAction writeaction;
    writeaction.getOutput()-> setFilePointer (auv_iv_fp);
    writeaction.apply (AUV_node);
    fclose (auv_iv_fp);
    cout << "writeaction.apply (AUV_node) => auv.iv complete." << endl;

    // WriteAction writes scene graph to file
    FILE * auv_vw_iv_fp = fopen ("auv_vw.iv", "w");
    writeaction.getOutput()-> setFilePointer (auv_vw_iv_fp);
    writeaction.apply (root);
    fclose (auv_vw_iv_fp);
    cout << "writeaction.apply (root) => auv_vw.iv complete." << endl;

    DIS_net_open ();
    atexit (DIS_net_close); // ensure port is reclosed on exit. tested sat.
    current_clock = clock (); // initialize

    // A TimerSensor updates the object with DIS postures and performs redraws
    SoTransform * dummy_xform = new SoTransform;
    SoTimerSensor * DIS_Redraw_Sensor = new SoTimerSensor( DIS_Redraw_Callback,
                                                            dummy_xform );
    DIS_Redraw_Sensor->setInterval ( 0.10 ); // seconds
    DIS_Redraw_Sensor->schedule ();

    // system ("rm sounds/nps_auv.au");
    // system ("www -o sounds/nps_auv.au
    file:///taurus.cs.nps.navy.mil/pub/auv/nps_auv.au");
    // system ("www -o sounds/nps_auv.au
    http://www_tios.cs.utwente.nl/say/?Naval+Postgraduate+School,Autonomous+Underwater+Veh
    icle");
    // system ("sfplay sounds/nps_auv.au &");

    if (PRINTDIALOG == TRUE)
    {
        // Print dialog widget: Inventor training manual p. 9-9
        SoXtPrintDialog *printDialog = new SoXtPrintDialog;
        printDialog->setSceneGraph (root);
        printDialog->show ();
    }

```

```

/* coloreditor not found?!
if (BACKGROUNDCOLORDIALOG == TRUE)
{
    // Build the color editor in its own window
    SoXtColorEditor *color_editor = new SoXtColorEditor;
    color_editor->build();
    color_editor->setTitle( "AUV viewer background color" );
    // Add a callback for when the color changes
    color_editor->addColorChangedCallback( colorEditorCB, // the callback
                                          viewer ); // user data to be passed

    SbColor lightbluecolor( .0, .5, .75 );
    viewer->setBackgroundColor( lightbluecolor );
    color_editor->setColor      ( lightbluecolor );
    color_editor->show();      // Display the color editor
}

// Uncomment which viewer you want to use:
SoXtExaminerViewer * viewer = new SoXtExaminerViewer;
// SoXtFlyViewer      * viewer = new SoXtFlyViewer;
// SoXtPlaneViewer    * viewer = new SoXtPlaneViewer;
// SoXtWalkViewer      * viewer = new SoXtWalkViewer;

viewer->setSceneGraph( root );
viewer->setTitle("NPS AUV Virtual World");
viewer->show();
// XtRealizeWidget ( ViewerWindowWidget ); // mini window junk
SoXt::mainLoop(); // loop forever, sending events to the scene graph
}
// end of viewer.C
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

```

C. *Makefile* for Object-Oriented Real-Time Graphics Viewer

```
#!/smake

PROGRAM = viewer

C++FILES = viewer.C

# /usr/include/make/commondefs and /usr/include/make/commonrules
# Define some useful Makefile rules. For example, they
# defines a 'clean' target, so you can type 'make clean'
# to remove all .o files (or other files generated during
# compilation). See the file /usr/include/make/commonrules for
# documentation on what targets are supported.

include /usr/include/make/commondefs

TARGETS = $(PROGRAM)

OBJECTS = viewer.o

# Libraries to link with:

LLDLIBS = -lInventorXt

#####
# DIS includes

INCS      = -I../DIS.mcast/h
LIB_DIR   = -L../DIS.mcast/src
LIB       = ../DIS.mcast/src/libdis_client.a
LIB_ARG   = -ldis_client
HDR_PATH  = ../DIS.mcast/h/
HDRS      = $(HDR_PATH)pdu.h $(HDR_PATH)disdefs.h

#####

default: $(TARGETS)

include $(COMMONRULES)

$(TARGETS): $(OBJECTS)
    cc $(C++FILES) -o $@ $(OBJECTS) $(LDFLAGS) $(LIB) $(LIB_DIR) $(INCS) \
    $(LIB_ARG) $(LLDLIBS)

# modified from patton:/usr/share/src/Inventor/samples/clock/Makefile

# updated 2 October 94 Don Brutzman
```

V. UNDERWATER VIRTUAL WORLD HYDRODYNAMICS

A. Introduction

Structuring the model design problem was the key to comprehensible implementation. A straightforward hierarchy follows. Posture is common to all vehicles and can be represented either by Euler angle rotations, by a homogenous transformation matrix (Fu 87) (Foley, van Dam 90), or by quaternions (Cooke 92). Forces and accelerations acting upon a rigid body, if modeled, are related by dynamics equations of motion corresponding to each spatial degree of freedom. A rigid body is further subject to kinematics equations of motion which combine velocities with postures in strictly defined ways regardless of vehicle type or environmental dimensionality. A networked rigid body which communicates with other entities via DIS needs to calculate postures, optional linear and rotational velocities, and (again optional) linear accelerations (IEEE 93). Such a DIS-networked rigid body has identical capabilities regardless of vehicle type.

An entity dynamics component for a real-time networked virtual world combines the functionality of rigid bodies and DIS networking with the dynamics equations of motion (forces and accelerations) unique to a specific vehicle type. This structured hierarchy of relationships between posture representations, rigid bodies, DIS networking and dynamics equations of motion led to the general model class diagram which appears in Figure 1.

The compartment boxes within Figure 1 delineate the functionality of class components. The first compartment is class name. The second compartment indicates member data fields, which are the data structures encapsulated by the object. The third compartment indicates object methods (functions) which effectively occur instantaneously. The fourth compartment includes methods (functions) which are time-consuming, either from the perspective of simulation clock duration or actual delay due to network latency. Adapted from the Object-Oriented Simulation Pictures

(OOSPICs) design and testing methodology (Bailey 94), this diagramming approach is very useful because it simplifies presentation of key object relationships and clarifies hierarchy design. Of particular value is the explicit specification of temporal relationships, which are critical to success in a real-time system and are often overlooked in complex system design. An example object template which adapts the OOSPICs methodology from *MODSIM* programming language to *C++* appears as Figure 2. A key for OOSPIC arrow conventions is included in Figure 3 (Bailey 94). Although *C++* OOSPICs are not provided for each class, inspection of specifications in the accompanying source code reveals that every class follows the structural layout presented in Figure 1.

Hydrodynamics Model Class Hierarchy

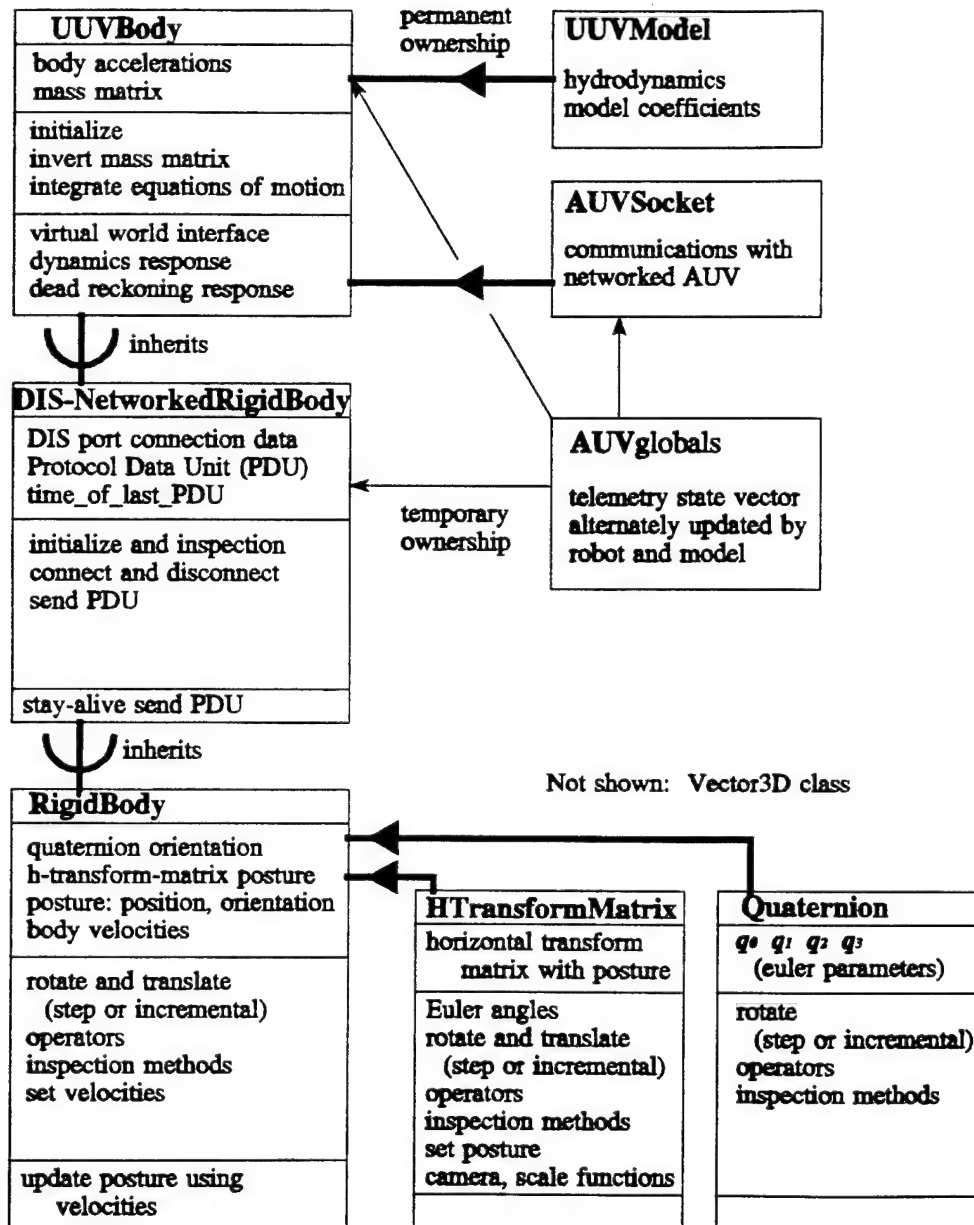


Figure 1. General real-time DIS-networked hydrodynamics model class hierarchy.

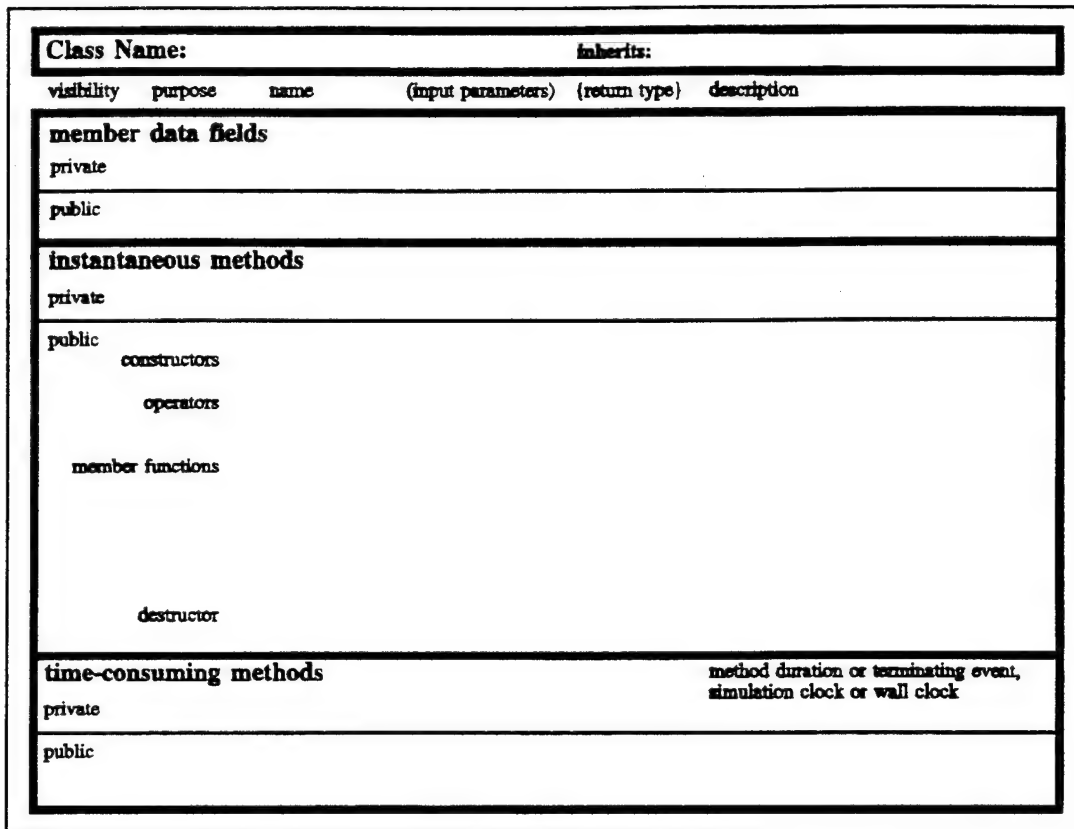


Figure 2.

OOSPIC class diagram template for **C++** class definitions. Separation of class name, data fields, instantaneous methods and temporal methods clarifies class functionality and design.

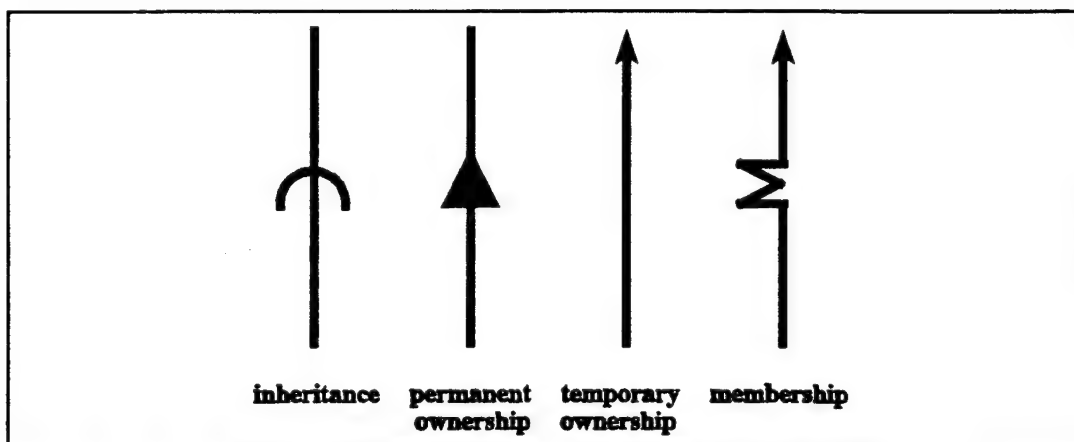


Figure 3.

Object-Oriented Simulation Pictures (OOSPICs) arrow conventions.

The structure of the general real-time DIS-networked dynamics model presented here appears to be applicable to vehicles of arbitrary type. Documented source code for each member of the class hierarchy matches the equations and algorithms presented in this work, and also follows the structure appearing in Figure 2 (Brutzman 94). Future work of interest in model design includes directly porting this model to emulate the characteristics of other underwater vehicles, adapting the model to accommodate dissimilar vehicle entities, porting the model into robot software as an on-board hydrodynamics response predictor, and investigating extensions to the model to support visualization, validation and verification of model relationships against archived or live data records of actual vehicle dynamics performance.

B. *dynamics*.C Virtual World Interface and Top-Level Hydrodynamics

The *dynamics* program is the server connection to the underwater virtual world. It must be started prior to the robot *execution* program so that the robot has a virtual world to connect to. *dynamics* also provides a user interface for setting ocean currents, multicast network parameters and hydrodynamics class library test routines. The user menu appears in Figure 4.

The *dynamics* program has a text-only user interface in order to reduce processor loading, maximize portability and facilitate remote operation. The menu option to reset multicast group parameters permits starting a virtual world channel using collision-free parameters automatically chosen by the MBone *sd* session directory application. The menu option for ocean currents accepts a constant 3D vector. Extending the overall functionality of the underwater virtual world is accomplished by building hooks between new models (such as time-varying ocean currents) and the *dynamics* program. New models can either be embedded directly within *dynamics*, or can be distributed and communicate via sockets.

```
dude:/n/dude/work/brutzman/dynamics>> dynamics

-----
Dynamics classes test selections

    L loop_test_with_execution_level ();
    M Multicast parameter input
      ttl=15, group address=224.2.121.93, port=3111
    O Ocean current vector reset
      <0, 0, 0>
    H Hmatrix/quaternion exerciser
    R Rotation of quaternion & Hmatrix using p q r
    D Defaults
    I Invert matrix test
    E dEad_reckon_test_with_execution_level
    P PDU_skip_interval change (from 1)
    T Toggle TRACE = 0
    C DIS_net_close ();
    Q Quit

Enter choice: _
```

Figure 4. *dynamics* virtual world server: user interface.

```

/////////////////////////////////////////////////////////////////
/*
Program:      dynamics.C
Description:   hydrodynamics model and virtual world manager
Author:       Don Brutzman
Revised:      18 October 94
System:       Irix 5.2
Compiler:     ANSI C++
Compilation:  irix> CC  dynamics.C -lm -w -g -o dynamics
              [or] unix> make dynamics
              +w == Warn about all questionable constructs.
Advisors:     Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey
Lessons:      Need single char input without requiring <CR>
              Don't use 'static' for member data fields or mysterious linker
              eRrors result

```

Don't use << endl << endl more than once in a single cout call
 or a vague warning results with an invalid line number:
 'warning: ostream&ostream::operator <<(ostream&(*)
 (ostream&)) not inlined, called twice in an expression'

```

*/
/////////////////////////////////////////////////////////////////

#include <stdio.h>
#include <ctype.h>

#include "UUVBody.C"

#include <bstring.h>

/////////////////////////////////////////////////////////////////
// global data

char          port [ 6]; // pointer to MULTICAST_PORT
char          group [20]; // MULTICAST_GROUP;
int           int_ttl = 15; // time-to-live

char          choice = '*'; // dummy value to print menu first time

int           READ_MENU_CHOICE = TRUE;

/////////////////////////////////////////////////////////////////

void parse_command_line_flags (int argc, char ** argv)
    // command line arguments
{
    int index, i;

    // 3111 is npsnet 'standard' port
    strncpy (port, "3111", 4);
    strncpy (group, "224.2.121.93", 12);

    // cout << "[parse_command_line_flags start: # arguments = " << argc
    //      << "]" << endl;
    // cout << "[ ";
    // for (i = 0; i < argc; i++) cout << argv [i] << " ";
    // cout << "]" << endl;

    for (i = 1; i < argc; i++)
    {
        for (index = 0; index <= strlen (argv[i]); index++) // uppercase
            argv[i] [index] = toupper (argv[i] [index]);
    }

    // cout << "[parse_command_line_flags uppercase: # arguments = " << argc
    //      << "]" << endl;
    // cout << "[ ";
    // for (i = 0; i < argc; i++) cout << argv [i] << " ";
    // cout << "]" << endl;

    for (i = 1; i < argc; i++)
    {
        if      ((strcmp (argv[i], "TTL") == 0) ||
                 (strcmp (argv[i], "-TTL") == 0) ||
                 (strcmp (argv[i], "T") == 0) ||
                 (strcmp (argv[i], "-T") == 0))
        {
            if (i+1 >= argc )
                cout << "Insufficient parameters for TTL" << endl;
        }
    }
}

```

```

        else
        {
            int_ttl = atoi (argv[i+1]);
            cout << "dynamics: ttl reset to " << int_ttl
                << endl;
            i++;
        }
    }
    else if ((strcmp (argv[i], "PORT") == 0) ||
             (strcmp (argv[i], "-PORT") == 0) ||
             (strcmp (argv[i], "P") == 0) ||
             (strcmp (argv[i], "-P") == 0))
    {
        if ( i+1 >= argc )
            cout << "Insufficient parameters for PORT" << endl;
        else
        {
            bzero (port, 6);
            strcpy (port, argv[i+1]);
            cout << "dynamics: port reset to " << port
                << endl;
            i++;
        }
    }
    else if ((strcmp (argv[i], "GROUP") == 0) ||
             (strcmp (argv[i], "-GROUP") == 0) ||
             (strcmp (argv[i], "G") == 0) ||
             (strcmp (argv[i], "-G") == 0) ||
             (strcmp (argv[i], "ADDRESS") == 0) ||
             (strcmp (argv[i], "-ADDRESS") == 0) ||
             (strcmp (argv[i], "A") == 0) ||
             (strcmp (argv[i], "-A") == 0))
    {
        if ( i+1 >= argc )
            cout << "Insufficient parameters for GROUP ADDRESS" << endl;
        else
        {
            bzero (group, 20);
            strcpy (group, argv[i+1]);
            cout << "dynamics: group address reset to " << group
                << endl;
            i++;
        }
    }
    else if ((strcmp (argv[i], "LOOP") == 0) ||
             (strcmp (argv[i], "-LOOP") == 0) ||
             (strcmp (argv[i], "L") == 0) ||
             (strcmp (argv[i], "-L") == 0))
    {
        choice = 'L';
        READ_MENU_CHOICE = FALSE;
        cout << "dynamics: Loop test with execution level set " << endl;
    }
    else if ((strcmp (argv[i], "TRACE") == 0) ||
             (strcmp (argv[i], "-TRACE") == 0))
    {
        TRACE = TRUE;
        cout << "dynamics: TRACE is now on" << endl;
    }
    else
    {
        cout << "dynamics: unrecognized command flag " << argv[i] << endl;
    }
} // end for loop through command line parameters

```

```

// cout << "[parse_command_line_flags complete]" << endl;

return;

} // end parse_command_line_flags ()

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

void main ( int argc, char ** argv )
{
    double          a1,    b1,    c1,
                   x1,    y1,    z1,
                   p,     q,     r,          delta_time;

    int             done = FALSE;
    int             index, repetitions;

    Vector3D        vector1, vector2;

    Quaternion      quaternion1, quaternion2;

    Hmatrix         hmatrix1, hmatrix2;

    RigidBody       rigidbody1;

    DISNetworkedRigidBody disnetworkedrigidbody1;

    UUVBody         uuvbody1;

// main start

    parse_command_line_flags (argc, argv);

do
{
    if ( ! isspace (choice))
    {
        cout << endl;
        cout << "-----";
        cout << endl;
        cout << "Dynamics classes test selections" << endl;
        cout << "    L loop_test_with_execution_level ();" << endl;
        cout << "    M Multicast parameter input" << endl;
        cout << "        ttl=" << int_ttl << ", group address=" << group
        cout << "        ", port=" << port << endl;
        cout << "    O Ocean current vector reset " << endl;
        cout << "        <" << AUV_oceancurrent_u << ", "
        cout << "        << AUV_oceancurrent_v << ", "
        cout << "        << AUV_oceancurrent_w << ">" << endl;

        cout << "    H Hmatrix/quaternion exerciser" << endl;
        cout << "    R Rotation of quaternion & Hmatrix using p q r "
        cout << "        << endl;

        cout << "    D Defaults" << endl;
        cout << "    I Invert matrix test" << endl;
        cout << "    E dEad_reckon_test_with_execution_level" << endl;
        cout << "    P PDU_skip_interval change (from "
        cout << "        uuvbody1.PDU_skip_interval_value () << ")" << endl;
        cout << "    T Toggle TRACE = " << TRACE << endl;
        cout << "    C DIS_net_close ();" << endl;
        cout << "    Q Quit" << endl;
        cout << "Enter choice: ";
        cout << flush;
    }

    if (READ_MENU_CHOICE == TRUE)
    {

```

```

        // still not reading a single char properly :(
        // cin.get (choice);
        cin >> choice;
        cout << endl;
    }
    else cout << choice << endl;

    READ_MENU_CHOICE = TRUE;

    switch (choice)
    {
    case 'L': case 'l': //-----
        cout << "Loop test with execution level" << endl;

        uuvbody1.UUVBody_initialize      ();
        uuvbody1.set_ttl                  (int_ttl);
        uuvbody1.set_group                (group);
        uuvbody1.set_port                 (port);

        cout << "dynamics: uuvbody.loop_test_with_execution_level ()" << endl;

        uuvbody1.loop_test_with_execution_level ();

        choice = '*'; // dummy value to print keyboard menu
        break;

    case 'O': case 'o': //-----
        cout << " Ocean current vector reset " << endl;
        cout << " _____ " << endl;
        cout << endl;

        cout << "Enter AUV_oceancurrent in North direction: ";
        cin >> AUV_oceancurrent_u;
        cout << " new AUV_oceancurrent_u = " << AUV_oceancurrent_u << endl;
        cout << endl;

        cout << "Enter AUV_oceancurrent in East direction: ";
        cin >> AUV_oceancurrent_v;
        cout << " new AUV_oceancurrent_v = " << AUV_oceancurrent_v << endl;
        cout << endl;

        cout << "Enter AUV_oceancurrent in Downward direction: ";
        cin >> AUV_oceancurrent_w;
        cout << " new AUV_oceancurrent_w = " << AUV_oceancurrent_w << endl;
        cout << endl;

        choice = '*'; // dummy value to print keyboard menu
        break;

    case 'M': case 'm': //-----
        cout << " Multicast parameter input " << endl;
        cout << " _____ " << endl;
        cout << endl;

        cout << "Enter time to live ttl: ";
        cin >> int_ttl;
        cout << " new time to live ttl = " << int_ttl << endl;
        cout << endl;

        cout << "Enter group address: ";
        cin >> group;
        cout << " new group address = " << group << endl;
        cout << endl;
    }
}

```

```

cout << "Enter port:          ";
cin >> port;
cout << "    new port          = " << port << endl;
cout << endl;

choice = '*'; // dummy value to print keyboard menu
break;

case 'H': case 'h': //-----

    cout << "Hmatrix/quaternion exerciser:" << endl;

    cout << "Enter euler angles in degrees for object: ";
    cin >> a1 >> b1 >> c1;
    cout << " angles entered = <" << a1 << ", " << b1 << ", " << c1 << ">"
        << endl;

    quaternion1 = Quaternion (radians (a1), radians (b1), radians (c1));

    cout << "quaternion1: ";
    quaternion1.print ();
    quaternion1.normalize ();

    cout << endl;
    cout << "normalized:      " << quaternion1 << endl;

    vector2 = quaternion1.euler_angles ();
    cout << "euler angles1: " << vector2 << endl;

    cout << "phi theta psi1:" << quaternion1.phi_value  () << ", "
        << quaternion1.theta_value () << ", "
        << quaternion1.psi_value  () << endl;
    cout << "degrees:      " << degrees (quaternion1.phi_value  ()) << ", "
        << degrees (quaternion1.theta_value ()) << ", "
        << degrees (quaternion1.psi_value  ()) << endl;

    cout << endl;

    cout << "Enter vector positions for object: ";
    cin >> x1 >> y1 >> z1;

    vector1 = Vector3D (x1, y1, z1);
    cout << "vector1:      " << vector1 << endl;

    hmatrix1 = Hmatrix ( vector1, radians (a1), radians (b1), radians (c1));
    cout << "hmatrix1:      " << hmatrix1 << endl;

    cout << " hmatrix1 angles: " << degrees (hmatrix1.phi_value  ()) << ", "
        << degrees (hmatrix1.theta_value ()) << ", "
        << degrees (hmatrix1.psi_value  ()) << endl;

    choice = '*'; // dummy value to print keyboard menu
    break;

case 'R': case 'r': //-----

    cout << "Rotation" << endl;
    cout << endl;
    cout << "Enter euler angles in degrees for object: ";
    cin >> a1 >> b1 >> c1;

    quaternion1 = Quaternion (radians (a1), radians (b1), radians (c1));

    cout << "Enter rotation rates in degrees per sec <p, q, r>: ";
    cin >> p >> q >> r ;
    p = radians (p);
    q = radians (q);
    r = radians (r);

```

```

cout << "Enter repetitions and delta_time in seconds: ";
cin >> repetitions >> delta_time;

cout << "Enter vector positions for object: ";
cin >> x1 >> y1 >> z1;
vector1 = Vector3D (x1, y1, z1);

hmatrix1 = Hmatrix (vector1, radians (a1), radians (b1), radians (c1));
hmatrix2 = Hmatrix (vector1, radians (a1), radians (b1), radians (c1));

for (index=0; index <= repetitions; index++)
{
    cout << "quaternion = ";
    quaternion1.print ();
    cout << endl;
    cout << "quaternion1 angles = <"
        << degrees (quaternion1.phi_value ()) << ", "
        << degrees (quaternion1.theta_value ()) << ", "
        << degrees (quaternion1.psi_value ()) << ">" << endl;
    quaternion1.incremental_rotate (p, q, r, delta_time);

    cout << "    hmatrix1 angles = <" << degrees (hmatrix1.phi_value ())
        << ", " << degrees (hmatrix1.theta_value ())
        << ", " << degrees (hmatrix1.psi_value ())
        << ">" << endl;

    cout << "    hmatrix2 angles = <" << degrees (hmatrix2.phi_value ())
        << ", " << degrees (hmatrix2.theta_value ())
        << ", " << degrees (hmatrix2.psi_value ())
        << ">" << endl;

    cout << "hmatrix1 = " << hmatrix1 << endl;

    // two alternate methods can be tested:
    hmatrix1.incremental_rotation (p, q, r, delta_time);
    hmatrix2.rotate (p * delta_time, q * delta_time, r * delta_time);

    cout << "-----" << endl;
    cin.get (choice); // pause
}
choice = '*'; // dummy value to print keyboard menu
break;

case 'D': case 'd': //-----

    cout << "Defaults" << endl;
    cout << endl;

    vector1 = Vector3D ();
    quaternion1 = Quaternion ();
    hmatrix1 = Hmatrix ();

    cout << "Using << operators:" << endl;
    cout << "Default vector3D: " << vector1 << endl;
    cout << "Default quaternion: " << quaternion1 << endl;
    cout << "Default Hmatrix: " << hmatrix1;

    cout << "Using print methods:" << endl;
    cout << "Default vector3D: ";
    vector1.print ();
    cout << endl << "Default quaternion: ";
    quaternion1.print ();
    cout << endl << "Default Hmatrix: ";
    hmatrix1.print_hmatrix ();

    cout << endl;
    cout << "initializations & assignment:" << endl;

```

```

vector1      = Vector3D (1, 2, 3);
cout         << " Vector3D (1, 2, 3) == " << vector1 << endl;
quaternion1  = Quaternion (0, 0, 0);
cout         << " Quaternion (0, 0, 0) == " << quaternion1 << endl;
hmatrix1     = Hmatrix ( 40, 50, 60,
                        radians (0), radians (-90), radians (0) );
cout         << " Hmatrix ( 40, 50, 60, radians(0), radians(-90),"
                << " radians(0)) " << hmatrix1 << endl;

hmatrix1     = Hmatrix (Vector3D(40,50,60),
                        Vector3D(radians(0), radians(-90), radians(0)));
cout         << " Hmatrix (Vector3D(40, 50, 60),"
                << " Vector3D(radians (0), radians(-90), radians(0))) "
                << hmatrix1 << endl;

quaternion1  = Quaternion (radians (90), 0, 0) *
                Quaternion (0, 0, radians (90));
cout << "quaternion multiplication test <90,0,0> * <0,0,90> =>" << endl;
cout << " <" << degrees (quaternion1.phi_value ()) << ", "
        << degrees (quaternion1.theta_value ()) << ", "
        << degrees (quaternion1.psi_value ()) << ">" << endl;

rigidbody1   = RigidBody ();
cout << endl;
cout << " RigidBody () defaults printed using different methods:"
        << rigidbody1;
rigidbody1.print_rigidbody ();
cout << endl;

disnetworkedrigidbody1.DISNetworkedRigidBody_initialize ();
cout << " DISNetworkedRigidBody () defaults printed using "
        << "different methods:" << disnetworkedrigidbody1;
disnetworkedrigidbody1.print_networkedrigidbody ();
cout << endl;

cout << " UUVBody () defaults printed using different methods:"
        << uuvbody1;
uuvbody1.print_uuvbody ();

choice = '*'; // dummy value to print keyboard menu
break;

case 'I': case 'i': //-----
    cout << "Invert test: uuvbody.test_invert_matrix ()" << endl;
    uuvbody1.test_invert_matrix ();

    choice = '*'; // dummy value to print keyboard menu
    break;

case 'E': case 'e': //-----
    cout << "dEad reckoning test" << endl;
    cout << "uuvbody.dead_reckon_test_with_execution_level ():" << endl;
    uuvbody1.dead_reckon_test_with_execution_level ();

    choice = '*'; // dummy value to print keyboard menu
    break;

case 'T': case 't': //-----
    if (TRACE == 0) TRACE = 1;
    else TRACE = 0;

```

```

    cout << "Trace toggled, now TRACE = " << TRACE << " (" ;
    if (TRACE == 0) cout << "FALSE)";
    else             cout << "TRUE)";

    break;

case 'P': case 'p': //-----
    cout << "PDU_skip_interval change (from "
        << uuvbody1.PDU_skip_interval_value () << ")" << endl;

    cout << "PDUs will only be sent every <value> tenths of a second."
        << endl;
    cout << "Values less than 10 may make applications prone to crash."
        << endl;
    cout << "Enter new value:  ";

    int  new_skip_value;
    cin >> new_skip_value;
    cout << endl;

    uuvbody1.set_PDU_skip_interval (new_skip_value);

    break;

case 'C': case 'c': //-----
    cout << "Close" << endl;

    cout << "DIS_net_close ()" << endl;

    uuvbody1.DIS_net_close ();

    break;

case 'Q': case 'q': //-----
    cout << "Quit" << endl;
    done = TRUE;
    break;

default: //-----
    if ( ! isspace (choice)) cout << " ? unknown option.." << endl;
    break;

} // end: switch (choice)

} while (done == FALSE);

// normal exit
}
/////////////////////////////////////////////////////////////////

```

C. *AUVglobals.h* Robot Telemetry Variables

```
/////////////////////////////////////////////////////////////////
/*
Header file:      AUVglobals.H

Author:          Don Brutzman

Revised:         21 October 94

System:          Irix 5.2

Compiler:        ANSI C++

Compilation:      irix: make dynamics

Description:      Generalized vehicle state variables, customized for
                  NPS AUV II operation with virtual world hydrodynamics model

Advisors:        Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

References:      Brutzman, Donald P., "Integrated Simulation for Rapid
                  Development of Autonomous Underwater Vehicles,"
                  IEEE Oceanic Engineering Society Autonomous Underwater
                  Vehicle (AUV) Conference 92, Washington DC, June 4-5 1992,
                  pp. 3-10.

                  Brutzman, Donald P., "NPS AUV Integrated Simulator,"
                  Masters thesis, Naval Postgraduate School, Monterey CA,
                  March 1992.

                  Healey, Anthony J. and Lienard, David, "Multivariable
                  Sliding Mode Control for Autonomous Diving and Steering
                  of Unmanned Underwater Vehicles," IEEE Journal of Oceanic
                  Engineering, vol. 18 no. 3, July 1993, pp. 327-339,

                  Lewis, Edward V., editor, _Principles of Naval
                  Architecture volume III_, second revision, The Society of
                  Naval Architects and Marine Engineers, Jersey City
                  New Jersey, 1988, pp. 188-190 and 418-423.

*/
/////////////////////////////////////////////////////////////////

#ifndef AUVGLOBALS_H
#define AUVGLOBALS_H    // prevent errors if multiple #includes present

/*****
/* AUV telemetry state vector
/*
/* Note these are globals for direct access by any world model. Refer to
/* individual world models for details. Data hiding within a private object
/* is not necessary since all values are transient and superseded by actual
/* state when it occurs. Additionally, half of the state variables are
/* provided only by the AUV microprocessor socket, and the other half are
/* provided by respective world models. Thus global variables in this design
/* are not vulnerable to corruption and side effects, making data hiding
/* unnecessary.
*****/
```

```

// AUV-provided state variables - - - - -
static double AUV_time           = 0.0; // mission time
static double AUV_delta_rudder   = 0.0; // positive is bow rudder to starboard
static double AUV_delta_planes   = 0.0; // positive is bow planes to starboard
static double AUV_port_rpm       = 0.0; // propellor revolutions per minute
static double AUV_stbd_rpm       = 0.0; // propellor revolutions per minute

static double AUV_bow_vertical    = 0.0; // thruster volts 24V = 3820 rpm no load
static double AUV_stern_vertical  = 0.0; // thruster volts 24V = 3820 rpm no load
static double AUV_bow_lateral    = 0.0; // thruster volts 24V = 3820 rpm no load
static double AUV_stern_lateral   = 0.0; // thruster volts 24V = 3820 rpm no load

static double AUV_depth_cell      = 0.0; // pressure sensor, units are psid
static double AUV_heading         = 0.0; // gyrocompass in degrees
static double AUV_roll_angle      = 0.0; // matches intertial sensor onboard AUV
static double AUV_pitch_angle     = 0.0; // matches intertial sensor onboard AUV
static double AUV_roll_rate       = 0.0; // matches intertial sensor onboard AUV
static double AUV_pitch_rate      = 0.0; // matches intertial sensor onboard AUV
static double AUV_yaw_rate        = 0.0; // matches intertial sensor onboard AUV

static int    AUV_hour            = 0;   // internal AUV OS-9 system time, unused
static int    AUV_minute         = 0;
static int    AUV_second         = 0;

// Hydrodynamics-model-provided state variables - - - - -
static double AUV_x              = 0.0; // x    position in world coordinates
static double AUV_y              = 0.0; // y    position in world coordinates
static double AUV_z              = 0.0; // z    position in world coordinates
static double AUV_phi            = 0.0; // roll  posture in world coordinates
static double AUV_theta          = 0.0; // pitch posture in world coordinates
static double AUV_psi            = 0.0; // yaw   posture in world coordinates

static double AUV_x_dot          = 0.0; // Euler velocity along North-axis
static double AUV_y_dot          = 0.0; // Euler velocity along East-axis
static double AUV_z_dot          = 0.0; // Euler velocity along Depth-axis
static double AUV_phi_dot        = 0.0; // Euler rotation rate about North-axis
static double AUV_theta_dot      = 0.0; // Euler rotation rate about East-axis
static double AUV_psi_dot        = 0.0; // Euler rotation rate about Depth-axis

static double AUV_u              = 0.0; // surge linear velocity along x-axis
static double AUV_v              = 0.0; // sway linear velocity along y-axis
static double AUV_w              = 0.0; // heave linear velocity along z-axis
static double AUV_p              = 0.0; // roll angular velocity about x-axis
static double AUV_q              = 0.0; // pitch angular velocity about y-axis
static double AUV_r              = 0.0; // yaw angular velocity about z-axis

static double AUV_u_dot          = 0.0; // linear acceleration along x-axis
static double AUV_v_dot          = 0.0; // linear acceleration along y-axis
static double AUV_w_dot          = 0.0; // linear acceleration along z-axis
static double AUV_p_dot          = 0.0; // angular acceleration about x-axis
static double AUV_q_dot          = 0.0; // angular acceleration about y-axis
static double AUV_r_dot          = 0.0; // angular acceleration about z-axis

static double AUV_oceancurrent_u = 0.0; // Ocean current rate along North-axis
static double AUV_oceancurrent_v = 0.0; // Ocean current rate along East-axis
static double AUV_oceancurrent_w = 0.0; // Ocean current rate along Depth-axis

```

```
// Prior time loop saved variables - - - - -
```

```
static double AUV_time_prior      = 0.0; // mission time

static double AUV_x_prior         = 0.0; // x    position in world coordinates
static double AUV_y_prior         = 0.0; // y    position in world coordinates
static double AUV_z_prior         = 0.0; // z    position in world coordinates

static double AUV_phi_prior       = 0.0; // roll  posture in world coordinates
static double AUV_theta_prior     = 0.0; // pitch posture in world coordinates
static double AUV_psi_prior       = 0.0; // yaw   posture in world coordinates
```

```
// Sonar model provided state variables - - - - -
```

```
static double AUV_ST1000_bearing = 0.0; // ST_1000 conical pencil beam bearing
static double AUV_ST1000_range   = 0.0; // ST_1000 conical pencil beam range
static double AUV_ST1000_strength = 0.0; // ST_1000 conical pencil beam strength
const double AUV_ST1000_x_offset = 3.5; // ST_1000 longitudinal location in feet

static double AUV_ST725_bearing = 0.0; // ST_725 1 x 24 sector beam bearing
static double AUV_ST725_range   = 0.0; // ST_725 1 x 24 sector beam range
static double AUV_ST725_strength = 0.0; // ST_725 1 x 24 sector beam strength
const double AUV_ST725_x_offset = 3.5; // ST_725 longitudinal location in feet
```

```
// Model-wide global variables and constants - - - - -
```

```
static int TRACE          = 0;          /* 1 = trace on, 0 = trace off */

#define TRUE 1
#define FALSE 0

#define PI 3.1415926535897932

/*****/

#endif // endif_H
```

D. *UUVModel.h* Hydrodynamics Model Coefficients

```
////////////////////////////////////
/*
Program:      UUVmodel.H
Author:       Don Brutzman
Revised:      26 October 94
System:       Irix 5.2
Compiler:     ANSI C++
Compilation:  irix> make dynamics
              irix> CC UUVmodel.H +w

              +w == Warn about all questionable constructs.

Debugging:    gravyl:~brutzman/dynamics>> lint UUVmodel.h
Advisors:     Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey
References:   Healey, Anthony J. and Lienard, David, "Multivariable
              Sliding Mode Control for Autonomous Diving and Steering
              of Unmanned Underwater Vehicles," IEEE Journal of Oceanic
              Engineering, vol. 18 no. 3, July 1993, pp. 327-339,

              Lewis, Edward V., editor, _Principles of Naval
              Architecture volume III_, second revision, The Society of
              Naval Architects and Marine Engineers, Jersey City
              New Jersey, 1988, pp. 188-190 and 418-423.

              Gertler, Morton and Hagen, Grant R., _Standard Equations
              of Motion for Submarine Simulation_, Naval Ship
              Research and Development Center (NSRDC) Research and
              Development Report 2510, Washington DC, June 1967.

              Smith, N.S., Crane J.W. and Summey, D.C., _SDV Simulator
              Hydrodynamic Coefficients_, Naval Coastal Systems Center
              (NCSC), Panama City Florida, June 1978. Declassified.

              Marco, David. "Slow Speed Control and Dynamic Positioning
              of an Autonomous Vehicle," Ph.D. dissertation,
              Naval Postgraduate School, Monterey California, March 1995.

              Bahrke, Fredric G., "On-Line Identificaton of the Speed,
              Steering and Diving Response Parameters of an Autonomous
              Underwater Vehicle from Experimental Data," Master's Thesis,
              Naval Postgraduate School, Monterey California, March 1992.

              Warner, David C., "Design, Simulation and Experimental
              Verification of a Computer Model and Enhanced Position
              Estimator for the NPS AUV II," Master's Thesis,
              Naval Postgraduate School, Monterey California, December 1991.

Notes:        const definitions are for software engineering reliability
              they can be changed to variables if coefficient modification
              becomes desirable

*/
////////////////////////////////////

#ifndef UUVMODEL_H
#define UUVMODEL_H    // prevent errors if multiple #includes present
```



```

const double x_bow_vertical = 1.41 ; // ft Marco 17" measured 13.0"
const double x_stern_vertical = - 1.41 ; // ft Marco - 17" measured - 21.0"
const double x_bow_lateral = 1.92 ; // ft Marco 23" measured 19.0"
const double x_stern_lateral = - 1.92 ; // ft Marco - 23" measured - 26.0"

const double y_port_propeller = - 0.313; // ft Marco - 4" measured - 3.75"
const double y_stbd_propeller = 0.313; // ft Marco 4" measured 3.75"

#endif

//-----//
// Surge equation of motion coefficients //

const double X_u_dot = -2.82E-3 ; // Linear force coefficients acting in
const double X_v_dot = 0.0 ; // the longitudinal body axis
const double X_w_dot = 0.0 ; // with respect to subscripted
const double X_p_dot = 0.0 ; // motion components
const double X_q_dot = 0.0 ; //
const double X_r_dot = 0.0 ; //

const double X_uu = 0.0 ; //
const double X_vv = 0.0 ; // old -1.743E-2 SDV-9 holdover?
const double X_ww = 0.0 ; //
const double X_pp = 0.0 ; //
const double X_qq = 0.0 ; //
const double X_rr = 0.0 ; // old -7.53E-3 SDV-9 holdover?

const double X_prop = 7.78E-3 ; // X_prop "constant" no longer
applicable

const double X_rb = 0.283 * L; //
const double X_rs = -0.377 * L; //

const double X_uu_delta_b_delta_b = -1.018E-2 ; // drag due to bow plane
const double X_uu_delta_s_delta_s = -1.018E-2 ; // drag due to stern plane
const double X_uu_delta_r_delta_r = -1.018E-2 ; // drag due to rudder

const double X_pr = 0.0 ; // (these aren't in Bahrke thesis model)
const double X_wq = 0.0 ; //
const double X_vp = 0.0 ; //
const double X_vr = 0.0 ; //

const double X_uq_delta_bow = 0.0 ; //
const double X_uq_delta_stern = 0.0 ; //
const double X_ur_delta_rudder = 0.0 ; //
const double X_uv_delta_rudder = 0.0 ; //
const double X_uw_delta_bow = 0.0 ; //
const double X_uw_delta_stern = 0.0 ; //

const double X_qdsn = 0.0 ; // no longer used in new model
const double X_wdsn = 0.0 ; // no longer used in new model
const double X_dsdsn = 0.0 ; // no longer used in new model

const double speed_per_rpm = 2.0 / 700.0 ; // steady state: 0.0028571429
// = (2.0 feet/sec) per 700 rpm
const double C_d0 = 0.00778 ; //

//-----//
// Sway equation of motion coefficients //

const double Y_u_dot = 0.0 ; // Linear force coefficients acting in
const double Y_v_dot = -3.43E-2 ; // the athwartships body axis
const double Y_w_dot = 0.0 ; // with respect to subscripted
const double Y_p_dot = 0.0 ; // motion components
const double Y_q_dot = 0.0 ; //
const double Y_r_dot = -1.78E-3 ; //

```

```

const double Y_uu = 0.0 ; //
const double Y_uv = -1.07E-1 ; //
const double Y_uw = 0.0 ; //
const double Y_up = 0.0 ; //
const double Y_uq = 0.0 ; //
const double Y_ur = 0.0 ; // Warner = 1.187E-2; Bahrke = 0.0

const double Y_uu_delta_rb = 1.18E-2 ; // Marco = 1.241E-2; Bahrke = 1.18E-2
const double Y_uu_delta_rs = 1.18E-2 ; // Marco = 1.241E-2; Bahrke = 1.18E-2

const double Y_pq = 0.0 ; // (these aren't in Bahrke thesis model)
const double Y_qr = 0.0 ; //
const double Y_vq = 0.0 ; //
const double Y_wp = 0.0 ; //
const double Y_wr = 0.0 ; //
const double Y_vw = 0.0 ; //

const double C_dy = 0.5 ; //

//-----//
// Heave equation of motion coefficients //
const double Z_u_dot = 0.0 ; // Linear force coefficients acting in
const double Z_v_dot = 0.0 ; // the vertical body axis
const double Z_w_dot = -9.34E-2 ; // with respect to subscripted
const double Z_p_dot = 0.0 ; // motion components
const double Z_q_dot = -2.53E-3 ; //
const double Z_r_dot = 0.0 ; //

const double Z_vv = 0.0 ; //
const double Z_uw = -7.844E-1 ; //
const double Z_up = 0.0 ; //
const double Z_uq = 0.0 ; // Marco = -7.013E-2; Bahrke = 0.0
const double Z_rr = 0.0 ; //
const double Z_pp = 0.0 ; //

const double Z_uu_delta_b = - 2.11E-2 ; //
const double Z_uu_delta_s = - 2.11E-2 ; //

const double Z_pr = 0.0 ; // (these aren't in Bahrke thesis model)
const double Z_vp = 0.0 ; //
const double Z_vr = 0.0 ; //

const double Z_qn = 0.0 ; // no longer used in new model
const double Z_wn = 0.0 ; // no longer used in new model
const double Z_dsn = 0.0 ; // no longer used in new model

const double C_dz = 0.6 ; //

//-----//
// Roll equation of motion coefficients //
const double K_u_dot = 0.0 ; // Angular force coefficient acting
const double K_v_dot = 0.0 ; // about the longitudinal body axis
const double K_w_dot = 0.0 ; // with respect to subscripted
const double K_p_dot = -2.4E-4 ; // motion components
const double K_q_dot = 0.0 ; //
const double K_r_dot = 0.0 ; //

const double K_uu = 0.0 ; //
const double K_uv = 0.0 ; //
const double K_uw = 0.0 ; //
const double K_up = -5.4E-3 ; // surge-related roll damping drag
const double K_uq = 0.0 ; //
const double K_ur = 0.0 ; //

const double K_uu_planes = 0.0 ; // (these aren't in Bahrke thesis model)

```

```

const double K_pg = 0.0 ; //
const double K_qr = 0.0 ; //
const double K_vq = 0.0 ; //
const double K_wp = 0.0 ; //
const double K_wr = 0.0 ; //
const double K_vw = 0.0 ; //
const double K_prop = 0.0 ; // K_prop "constant" no longer applicable

const double K_pn = 0.0 ; // no longer used in new model

const double K_pp = -2.02E-2 ; // test value for p-squared damping
// static roll damping drag
// 100 * Healey minimal estimate
// (-2.02E-4)

const double K_p = K_pp/57.3 ; // estimate based on quadratic term
// (K_pp) equivalent damping at 1 deg/sec

//-----//
// Pitch equation of motion coefficients //
const double M_u_dot = 0.0 ; // Angular force coefficient acting
const double M_v_dot = 0.0 ; // about the athwartships body axis
const double M_w_dot = -2.53E-3 ; // with respect to subscripted
const double M_p_dot = 0.0 ; // motion components
const double M_q_dot = -6.25E-3 ; //
const double M_r_dot = 0.0 ; //

const double M_uu = 0.0 ; //
const double M_vv = 0.0 ; //
const double M_uw = 0.0 ; //
const double M_pp = 0.0 ; //
const double M_rr = 0.0 ; //

const double M_uq = -1.53E-2 ; // surge-related pitch damping drag ***

const double M_uu_delta_bow = - 0.283 * L * Z_uu_delta_b;
// note (-) Z_uu_delta_b
// = 0.043602433

const double M_uu_delta_stern = + 0.377 * L * Z_uu_delta_s;
// note (-) Z_uu_delta_s
// = - 0.058085219

const double M_pr = 0.0 ; // (these aren't in Bahrke thesis model)
const double M_vp = 0.0 ; //
const double M_vr = 0.0 ; //
const double M_prop = 0.0 ; // M_prop "constant" no longer applicable

const double M_qn = 0.0 ; // no longer used in new model
const double M_wn = 0.0 ; // no longer used in new model
const double M_dsn = 0.0 ; // no longer used in new model

const double M_qq = -7.00E-3 ; // slightly larger than N_rr estimate
// test value for q-squared
// static pitch damping drag
// estimated M_qq ~ K_pp * length / width
// Torsiello ~ 0.005* 7.3' / 10.1' = .005

const double M_q = M_qq / 57.3; // estimate based on quadratic term
// (M_qq) equivalent damping at 1 deg/sec

//-----//
// Yaw equation of motion coefficients //

```

```

const double N_u_dot = 0.0 ; // Angular force coefficient acting
const double N_v_dot = -1.78E-3 ; // about the vertical body axis
const double N_w_dot = 0.0 ; // with respect to subscripted
const double N_p_dot = 0.0 ; // motion components
const double N_q_dot = 0.0 ; //
const double N_r_dot = -4.7E-4 ; //

const double N_uu = 0.0 ; //
const double N_uv = 0.0 ; // Marco = -7.69E-3;
const double N_uw = 0.0 ; //
const double N_up = 0.0 ; //
const double N_uq = 0.0 ; //
const double N_ur = -3.90E-3 ; // surge-related yaw damping drag

// N_uu_delta_rb and N_uu_delta_rs not symmetric due to different moment arms

// const double N_uu_delta_rb = 1.3259 ; // Marco
// const double N_uu_delta_rs = 1.7663 ; // Marco

const double N_uu_delta_rb = 0.283 * L * Y_uu_delta_rb; // Bahrke =
0.02437762
const double N_uu_delta_rs = 0.377 * L * Y_uu_delta_rs; // Bahrke =
0.03247478

const double N_prop = 0.0 ; // Normally 0.0 yaw moment due to paired
// counter-rotating propellers;
// however N_prop is not zero if propellor rpms are independent
// thus yaw equation of motion now has yaw moments due to propellers
// and N_prop "constant" is no longer applicable

const double N_pg = 0.0 ; // (these aren't in Bahrke thesis model)
const double N_gr = 0.0 ; //
const double N_vg = 0.0 ; //
const double N_wp = 0.0 ; //
const double N_wr = 0.0 ; //
const double N_vw = 0.0 ; //

const double N_rr = -5.48E-3 ; // Torsiello value p.113 adjusted for L^5
// correction; static yaw damping drag
// estimated N_rr ~ M_qq * height / width
// = .040 * 10.1" / 16.5"
// = 0.005
// Torsiello: 0.005
// Healey: N_rr ~ M_qq

// alternate N_rr = 2 * 2# * 1.92' / (rho/2 L^5 * r_max * r_max) => 0.0048473244
// using r_max = 16 deg/sec Torsiello which is consistent

const double N_r = N_rr / 57.3; // estimate based on quadratic term
// (N_rr) equivalent damping at 1 deg/sec

//-----//

// from Dave Marco's dynamics model:
// DEFINE THE LENGTH X, BREADTH BR, AND HEIGHT HH TERMS

double xx [15] = {
-43.9/12.0,
-39.2/12.0,
-35.2/12.0,
-31.2/12.0,
-27.2/12.0,
-10.0/12.0,
0.0/12.0,
10.0/12.0,
26.8/12.0,
32.0/12.0,

```

```

37.8/12.0,
40.8/12.0,
42.3/12.0,
43.3/12.0,
43.7/12.0);

double hh [15] = {
0.0/12.0,
2.7/12.0,
5.2/12.0,
7.6/12.0,
10.1/12.0,
10.1/12.0,
10.1/12.0,
10.1/12.0,
10.1/12.0,
9.6/12.0,
7.6/12.0,
5.6/12.0,
4.2/12.0,
2.3/12.0,
0.0/12.0);

double bb [15] = {
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
16.5/12.0,
15.5/12.0,
12.4/12.0,
9.5/12.0,
7.0/12.0,
4.0/12.0,
0.0/12.0);

//-----//

#endif // UVVMODEL_H

```

E. *UUVBody.C* Unmanned Underwater Vehicle Networked Rigid Body

```
/////////////////////////////////////////////////////////////////
/*
Program:          UUVBody.C

Description:      Six degree-of-freedom underwater vehicle hydrodynamics
                  based on Healey model

Revised:         28 October 94

System:          Irix 5.2

Compiler:        ANSI C++

Compilation:      irix> make dynamics
                  irix> CC UUVBody.C -lm -c -g +w

                  -c == Produce binaries only, suppressing the link phase.
                  +w == Warn about all questionable constructs.

Advisors:        Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

Author:          Don Brutzman          brutzman@cs.nps.navy.mil
                  Code OR/Br
                  Naval Postgraduate School      (408) 656-2149 work
                  Monterey CA 93943-5000         (408) 656-2595 fax

References:      Healey, A.J. and Lienard, D., "Multivariable Sliding Mode
                  Control for Autonomous Diving and Steering of Unmanned
                  Underwater Vehicles," IEEE Journal of Oceanic Engineering,
                  vol. 18 no. 3, July 1993, pp. 327-339.

                  Yuh, J., "Modeling and Control of Underwater Robotic
                  Vehicle," IEEE Transactions on Systems, Man and Cybernetics,
                  vol. 20 no. 6, November/December 1990, pp. 1475-1483.

                  Press, William H., Teukolsky, Saul A., Vetterling,
                  William T. and Flannery, Brian P., "Numerical Recipes in C,"
                  second edition, Cambridge University Press, Cambridge
                  England, 1992.

                  Marco, David. "Slow Speed Control and Dynamic Positioning
                  of an Autonomous Vehicle," Ph.D. dissertation,
                  Naval Postgraduate School, Monterey California, March 1995.

                  Fossen, Thor I., _Guidance and Control of Ocean Vehicles_,
                  John Wiley and Sons, Chichester England, 1994.

Status:          Equations of motion tested satisfactorily,
                  verification against in-water tests remains.
                  Move utilities to math_utilities.c

Future work:     Comments and suggestions are welcome!

*/
/////////////////////////////////////////////////////////////////

#ifndef UUVBODY_C
#define UUVBODY_C    // prevent errors if multiple #includes present

char * DISCLIANT = "~/DIS.mcast/src/client -r &";
```

```

#include "SonarModel.C"
#include "UUVmodel.H"
#include "DISNetworkedRigidBody.C"

////////////////////////////////////////////////////////////////

class UUVBody : public DISNetworkedRigidBody
{
private:
Hmatrix Hprevious ;

// member data fields

double    current_uuv_time;

double    U;           // Linear & angular velocities
double    V;           //   in body coordinates
double    W;           //   (note: RigidBody is world coordinates)
double    P;
double    Q;
double    R;

double    u_dot;       // Linear & angular accelerations
double    v_dot;       //   in body coordinates
double    w_dot;
double    p_dot;
double    q_dot;
double    r_dot;

double    x_dot;       // Euler velocities, world coordinates
double    y_dot;
double    z_dot;

double    phi_dot;     // Euler rotation rates, world coordinates
double    theta_dot;
double    psi_dot;

double    mass [6][6]; // mass matrix acceleration coefficients
double    mass_inverse [6][6]; // mass matrix inverted
double    rhs [6];     // right-hand-sides of equations of motion
double    new_acceleration [6]; // product [mass_inverse][rhs]
double    new_velocity [6]; // (averaged_accelerations * dt)
// + old_velocities

// AUV telemetry state vector is located in "AUV_globals.h" file

public:
// member constructor and destructor functions
UUVBody
                                ();
~UUVBody
                                ()    { /* null body */ }

// operators
void    multiply6x6_6
                                (double    left_matrix    [6][6],
                                double    right_matrix    [6],
                                double    result_matrix    [6]);

```

```

void      multiply6x6_6x6      (double left_matrix [6][6],
                                double right_matrix [6][6],
                                double result_matrix [6][6]);

friend ostream& operator <<      (ostream& out, UUVBody& uuvb);

// inspection methods

void      print_uuvbody      ();

void      print_matrix6      (double output_matrix [6]);
void      print_matrix6x6    (double output_matrix [6][6]);

double    current_uuv_time_value      () const;

double    u_dot_value      () const;
double    v_dot_value      () const;
double    w_dot_value      () const;
double    p_dot_value      () const;
double    q_dot_value      () const;
double    r_dot_value      () const;

double    x_dot_value      () const;
double    y_dot_value      () const;
double    z_dot_value      () const;

// modifying methods

void      UUVBody_initialize      ();

void      set_current_uuv_time      (double new_current_uuv_time);

void      set_accelerations      (double new_u_dot,
                                double new_v_dot,
                                double new_w_dot,
                                double new_p_dot,
                                double new_q_dot,
                                double new_r_dot);

void      set_linear_accelerations      (double new_u_dot,
                                double new_v_dot,
                                double new_w_dot);

void      set_angular_accelerations      (double new_p_dot,
                                double new_q_dot,
                                double new_r_dot);

void      // vehicle socket communications with dynamics
loop_test_with_execution_level ();

void      // vehicle socket communications with no dynamics
dead_reckon_test_with_execution_level ();

void      swap      (double * a, double * b);

double    square      (double value);

double    nonzerosign      (double value);

void      clamp      (double * clampee,
                    double absolute_min,
                    double absolute_max,
                    char * name);

double    epsilon      ();

void      invert_mass_matrix      ();

```

```

void      test_invert_matrix      ();

void      calculate_mass_matrix   ();

void      integrate_equations_of_motion ();

};

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

//-----//
// constructor methods
//-----//

UUVBody::UUVBody () // default constructor
{
    Hprevious = Hmatrix ();

    RigidBody_initialize ();           // inherited method
    DISNetworkedRigidBody_initialize (); // inherited method

    current_uuv_time = 0.0;

    U      = 0.0;
    V      = 0.0;
    W      = 0.0;
    P      = 0.0;
    Q      = 0.0;
    R      = 0.0;

    u_dot  = 0.0;
    v_dot  = 0.0;
    w_dot  = 0.0;
    p_dot  = 0.0;
    q_dot  = 0.0;
    r_dot  = 0.0;

    x_dot  = 0.0;
    y_dot  = 0.0;
    z_dot  = 0.0;
    phi_dot = 0.0;
    theta_dot = 0.0;
    psi_dot = 0.0;

    for (int index = 0; index <= 5; index++) rhs [index] = 0.0;

    calculate_mass_matrix ();
    invert_mass_matrix   ();
}

//-----//
// operators
//-----//

ostream& operator << (ostream& out, UUVBody& uuvb)
{
    int row, col;

    uuvb.print_networkedrigidbody ();
    out << "current_uuv_time = " << uuvb.current_uuv_time << endl;
    out << "<u_dot, v_dot, w_dot, p_dot, q_dot, r_dot> = " << "<"
        << uuvb.u_dot << ", " << uuvb.v_dot << ", " << uuvb.w_dot << ", "
        << uuvb.p_dot << ", " << uuvb.q_dot << ", " << uuvb.r_dot << ">"
        << endl;

    out << "Mass matrix:" << endl;
}

```

```

    for (row = 0; row <= 5; row++)
    {
        out << "[";
        for (col = 0; col <= 5; col++)
        {
            out << uvvb.mass [row][col];
            if (col < 5) out << ", ";
            else out << "]" << endl;
        }
    }
    out << "Mass inverse matrix:" << endl;
    for (row = 0; row <= 5; row++)
    {
        out << "[";
        for (col = 0; col <= 5; col++)
        {
            out << uvvb.mass_inverse [row][col];
            if (col < 5) out << ", ";
            else out << "]" << endl;
        }
    }
    return (out);
}
//-----//

void UVBBody:: multiply6x6_6 (double left_matrix [6][6],
                             double right_matrix [6],
                             double result_matrix [6])
{
    int row, col;

    for (row = 0; row <= 5; row++)
    {
        result_matrix [row] = 0.0;
        for (col = 0; col <= 5; col++)
        {
            result_matrix [row] = result_matrix [row] +
                                left_matrix [row][col] * right_matrix [col];
        }
    }
}
//-----//

void UVBBody:: multiply6x6_6x6 (double left_matrix [6][6],
                                double right_matrix [6][6],
                                double result_matrix [6][6])
{
    int row, col, index;

    for (row = 0; row <= 5; row++)
    {
        for (col = 0; col <= 5; col++)
        {
            result_matrix [row][col] = 0.0;
            for (index = 0; index <= 5; index++)
            {
                result_matrix [row][col] = result_matrix [row][col] +
                                    left_matrix [row][index] * right_matrix [index][col];
            }
        }
    }
}
//-----//
// inspection methods

```

```

//-----//
void UUVBody:: print_uuvbody ()
{
    print_networkedrigidbody ();
    cout << "current_uuv_time" = " << current_uuv_time << endl;

    cout << "<U, U, W, P, Q, R> body = " << "<"
        << U << ", " << V << ", " << W << ", "
        << P << ", " << Q << ", " << R << ">" << endl;

    cout << "<u_dot, v_dot, w_dot, p_dot, q_dot, r_dot> body = " << "<"
        << u_dot << ", " << v_dot << ", " << w_dot << ", "
        << p_dot << ", " << q_dot << ", " << r_dot << ">" << endl;

    Vector3D euler_position_rates = Vector3D (x_dot, y_dot, z_dot);
    cout << "<x_dot, y_dot, z_dot> = " << euler_position_rates << endl;

    Vector3D euler_angular_rates = Vector3D (phi_dot, theta_dot, psi_dot);
    cout << "<phi_dot, theta_dot, psi_dot> = " << euler_angular_rates << endl;

    cout << "Mass matrix:" << endl;
    print_matrix6x6 (mass);

    cout << "Mass inverse matrix:" << endl;
    print_matrix6x6 (mass_inverse);

    cout << "Right-hand side (RHS) of equations of motion: ";
    print_matrix6 (rhs);
}
//-----//

void UUVBody:: print_matrix6 (double output_matrix [6])
{
    int row;

    cout << "[";
    for (row = 0; row <= 5; row++)
    {
        cout << output_matrix [row];
        if (row < 5) cout << ", ";
    }
    cout << "]" << endl;
}
//-----//

void UUVBody:: print_matrix6x6 (double output_matrix [6][6])
{
    int row, col;

    for (row = 0; row <= 5; row++)
    {
        cout << "[";
        for (col = 0; col <= 5; col++)
        {
            cout << output_matrix [row][col];
            if (col < 5) cout << ", ";
            else cout << "]" << endl;
        }
    }
}
//-----//

double UUVBody:: current_uuv_time_value ()
const
{
    return current_uuv_time;
}

```

```

}
//-----//

double UUVBody:: u_dot_value ()
const
{
    return u_dot;
}
//-----//

double UUVBody:: v_dot_value ()
const
{
    return v_dot;
}
//-----//

double UUVBody:: w_dot_value ()
const
{
    return w_dot;
}
//-----//

double UUVBody:: p_dot_value ()
const
{
    return p_dot;
}
//-----//

double UUVBody:: q_dot_value ()
const
{
    return q_dot;
}
//-----//

double UUVBody:: r_dot_value ()
const
{
    return r_dot;
}
//-----//

double UUVBody:: x_dot_value ()
const
{
    return x_dot;
}
//-----//

double UUVBody:: y_dot_value ()
const
{
    return y_dot;
}
//-----//

double UUVBody:: z_dot_value ()
const
{
    return z_dot;
}
//-----//
// modifying methods
//-----//

```

```

void UUVBody:: UUVBody_initialize ()
{
    RigidBody_initialize ();                // inherited method
    DISNetworkedRigidBody_initialize ();    // inherited method

    current_uuv_time = 0.0;

    U          = 0.0;
    V          = 0.0;
    W          = 0.0;
    P          = 0.0;
    Q          = 0.0;
    R          = 0.0;

    u_dot      = 0.0;
    v_dot      = 0.0;
    w_dot      = 0.0;
    p_dot      = 0.0;
    q_dot      = 0.0;
    r_dot      = 0.0;

    x_dot      = 0.0;
    y_dot      = 0.0;
    z_dot      = 0.0;
    phi_dot    = 0.0;
    theta_dot  = 0.0;
    psi_dot    = 0.0;

    for (int index = 0; index <= 5; index++) rhs [index] = 0.0;

    calculate_mass_matrix ();
    invert_mass_matrix   ();

    AUV_ST1000_bearing = 0.0; // ST_1000 conical pencil beam bearing
    AUV_ST1000_range   = 0.0; // ST_1000 conical pencil beam range
    AUV_ST1000_strength= 0.0; // ST_1000 conical pencil beam strength

    AUV_ST725_bearing  = 0.0; // ST_725 1 x 24 sector beam bearing
    AUV_ST725_range    = 0.0; // ST_725 1 x 24 sector beam range
    AUV_ST725_strength = 0.0; // ST_725 1 x 24 sector beam strength

    AUV_bow_vertical   = 0.0; // thruster volts 24V = 3820 rpm no load
    AUV_stern_vertical  = 0.0; // thruster volts 24V = 3820 rpm no load
    AUV_bow_lateral     = 0.0; // thruster volts 24V = 3820 rpm no load
    AUV_stern_lateral   = 0.0; // thruster volts 24V = 3820 rpm no load

    AUV_delta_rudder   = 0.0; // positive is bow rudder to starboard
    AUV_delta_planes    = 0.0; // positive is bow planes to starboard
    AUV_port_rpm        = 0.0; // propellor revolutions per minute
    AUV_stbd_rpm        = 0.0; // propellor revolutions per minute
}
//-----//

void UUVBody:: set_current_uuv_time (double new_current_uuv_time)
{
    current_uuv_time = new_current_uuv_time;
}
//-----//

void UUVBody:: set_accelerations (double new_u_dot, double new_v_dot,
                                   double new_w_dot, double new_p_dot,
                                   double new_q_dot, double new_r_dot)
{
    u_dot = new_u_dot;
    v_dot = new_v_dot;
    w_dot = new_w_dot;
}

```

```

    p_dot = new_p_dot;
    q_dot = new_q_dot;
    r_dot = new_r_dot;
}
//-----//

void UUVBody:: set_linear_accelerations (double new_u_dot, double new_v_dot,
                                         double new_w_dot)
{
    u_dot = new_u_dot;
    v_dot = new_v_dot;
    w_dot = new_w_dot;
}
//-----//

void UUVBody:: set_angular_accelerations (double new_p_dot, double new_q_dot,
                                          double new_r_dot)
{
    p_dot = new_p_dot;
    q_dot = new_q_dot;
    r_dot = new_r_dot;
}
//-----//
// vehicle socket communications tests
//-----//

void UUVBody:: loop_test_with_execution_level ()
{
    int read_from_socket_result = 0;
    int write_to_socket_result = 0;

    // print_uuvbody (); // diagnostic

    if (TRACE) cout << "[loop_test_with_execution_level start]" << endl;

    open_execution_level_socket (); // repeated calls should not reopen it

    cout << endl;
    cout << "To listen on default multicast port (on another machine): "
         << endl;
    cout << DISCLIENT << endl;
    cout << endl;

    cout << "DIS_net_open ():" << endl;
    DIS_net_open ();

    while (TRUE) // loop until break
    {
        read_from_socket_result = read_from_execution_level_socket ();

        if (read_from_socket_result == -4) // time/position/orientation received
        {
            cout << "position or orientation command received: <"
                 << AUV_time << "> <"
                 << AUV_x << ", " << AUV_y << ", " << AUV_z << "> <"
                 << AUV_phi << ", " << AUV_theta << ", " << AUV_psi << ">"
                 << endl;

            RigidBody_initialize ();

            Vector3D vector1 = Vector3D (AUV_x, AUV_y, AUV_z);

            hmatrix = Hmatrix (vector1,
                              radians (AUV_phi),
                              radians (AUV_theta),
                              radians (AUV_psi));
            hmatrix.print_hmatrix ();
        }
    }
}

```

```

        Hprevious = hmatrix;
    }
    else if (read_from_socket_result == TRUE) // valid report received
    {
        integrate_equations_of_motion ();

        if (DIS_net_write () == FALSE) break; // send out PDU, otherwise done

        test_tank_sonar_model (); // parallelize & generalize the sonar model

        write_to_execution_level_socket (); // send back full telemetry
    }

    if ((read_from_socket_result == -3) || // KILL signal was received
        (read_from_socket_result == -4) ) // position signal was received
    {
        cout << "KILL/position/orientation signal received, " << endl;
        cout << "freeze the AUV where it is." << endl;

        AUV_u      = 0.0; // surge linear velocity along x-axis
        AUV_v      = 0.0; // sway linear velocity along y-axis
        AUV_w      = 0.0; // heave linear velocity along x-axis
        AUV_p      = 0.0; // roll angular velocity about x-axis
        AUV_q      = 0.0; // pitch angular velocity about y-axis
        AUV_r      = 0.0; // yaw angular velocity about z-axis

        AUV_u_dot   = 0.0; // linear acceleration along x-axis
        AUV_v_dot   = 0.0; // linear acceleration along y-axis
        AUV_w_dot   = 0.0; // linear acceleration along x-axis
        AUV_p_dot   = 0.0; // angular acceleration about x-axis
        AUV_q_dot   = 0.0; // angular acceleration about y-axis
        AUV_r_dot   = 0.0; // angular acceleration about z-axis

        AUV_x_dot   = 0.0; // Euler velocity along North-axis
        AUV_y_dot   = 0.0; // Euler velocity along East-axis
        AUV_z_dot   = 0.0; // Euler velocity along Depth-axis
        AUV_phi_dot = 0.0; // Euler rotation rate about North-axis
        AUV_theta_dot = 0.0; // Euler rotation rate about East-axis
        AUV_psi_dot = 0.0; // Euler rotation rate about Depth-axis

        clock_t start_busywait_clock = clock ();
        while (clock () < start_busywait_clock + 1.0 * CLOCKS_PER_SEC)
        {
            /* busy wait */
        }
        write_to_socket_result = DIS_net_write ();
        cout << "freeze AUV PDU sent: " << write_to_socket_result << endl;
    }

    if (read_from_socket_result == -3) // KILL signal was received
    {
        cout << "KILL signal received, exit "
              << "UUVBody.loop_test_with_execution_level" << endl;

        if (TRACE) cout << "[loop_test_with_execution_level complete]"
              << endl;

        return; // all done
    }
}
// unreachable exit point
// shutdown_socket () must have been invoked already to exit preceding loop
} // loop_test_with_execution_level complete
//-----//

void UUVBody:: dead_reckon_test_with_execution_level ()

```

```

int read_from_socket_result = 0;
int write_to_socket_result = 0;

cout << endl;
cout << "To listen on default multicast port: " << endl;
cout << DISCLIENT << endl;
cout << endl;

open_execution_level_socket ();

cout << "DIS_net_open ()" << endl;
DIS_net_open ();

while (TRUE) // loop until break
{
    read_from_socket_result = read_from_execution_level_socket ();

    if ((read_from_socket_result == -2) || // shutdown signal was received
        (read_from_socket_result == -3)) // quit signal was received
    {
        cout << "shutdown signal received, freeze the AUV where it is"
            << endl;

        AUV_u      = 0.0; // surge linear velocity along x-axis
        AUV_v      = 0.0; // sway linear velocity along y-axis
        AUV_w      = 0.0; // heave linear velocity along x-axis
        AUV_p      = 0.0; // roll angular velocity about x-axis
        AUV_q      = 0.0; // pitch angular velocity about y-axis
        AUV_r      = 0.0; // yaw angular velocity about z-axis

        AUV_u_dot   = 0.0; // linear acceleration along x-axis
        AUV_v_dot   = 0.0; // linear acceleration along y-axis
        AUV_w_dot   = 0.0; // linear acceleration along x-axis
        AUV_p_dot   = 0.0; // angular acceleration about x-axis
        AUV_q_dot   = 0.0; // angular acceleration about y-axis
        AUV_r_dot   = 0.0; // angular acceleration about z-axis

        AUV_x_dot   = 0.0; // Euler velocity along North-axis
        AUV_y_dot   = 0.0; // Euler velocity along East-axis
        AUV_z_dot   = 0.0; // Euler velocity along Depth-axis
        AUV_phi_dot = 0.0; // Euler rotation rate about North-axis
        AUV_theta_dot = 0.0; // Euler rotation rate about East-axis
        AUV_psi_dot = 0.0; // Euler rotation rate about Depth-axis

        clock_t start_busywait_clock = clock ();
        while (clock () < start_busywait_clock + 1.0 * CLOCKS_PER_SEC)
        {
            /* busy wait */
        }
        write_to_socket_result = DIS_net_write ();
        cout << "freeze AUV PDU sent: " << write_to_socket_result << endl;

        if (read_from_socket_result == -3) // quit signal was received
        {
            cout << "quit signal received, freeze the AUV where it is" << endl;
            cout << " and rezero for another loop if necessary" << endl;

            UUVBody_initialize ();
        }
        break;
    }

    // equations of motion not integrated, execution level does dead reckoning
    if (DIS_net_write () == FALSE) break; // send out a PDU, otherwise done
}

```

```

        write_to_execution_level_socket ();          // note state vector preserved
    }
    // shutdown_socket () must have been invoked already to exit preceding loop

    // cout << "DIS_net_close ()" << endl;
    // DIS_net_close ();
}
//-----//
// vehicle dynamics functions
//-----//

void UUVBody:: swap (double * a, double * b)
{
    double temp = * a;
    * a      = * b;
    * b      = temp;
}
//-----//

double UUVBody:: square (double value)
{
    return (value * value);
}
//-----//

double UUVBody:: nonzerosign (double value)
{
    if (value != 0.0) return  sign (value);
    else               return  + 1.0;
}
//-----//

void UUVBody:: clamp (double * clampee, double absolute_min,
                     double absolute_max, char * name)
{
    double new_value, local_min, local_max;

    if ((absolute_max == 0.0) && (absolute_min == 0.0)) return; // no clamp
    if (absolute_max >= absolute_min) // ensure min & max used in proper order
    {
        local_min = absolute_min;
        local_max = absolute_max;
    }
    else
    {
        local_min = absolute_max;
        local_max = absolute_min;
    }
    if ((* clampee) > local_max)
    {
        new_value = local_max;

        cout << "clamping " << name << " from "
              << * clampee << " to " << new_value << endl;

        * clampee = new_value;
    }
    if ((* clampee) < local_min)
    {
        new_value = local_min;

        cout << "clamping " << name << " from "
              << * clampee << " to " << new_value << endl;

        * clampee = new_value;
    }
}

```



```

        if (ipiv [j] != 1)
        {
            for (k = 0; k <= 5; k++)
            {
                if (ipiv [k] == 0)
                {
                    if (fabs (mass_copy [j][k]) >= big)
                    {
                        big = fabs (mass_copy [j][k]);
                        row = j;
                        col = k;
                    }
                }
                else if (ipiv [k] > 1)
                    cout << "Error:  singular mass matrix" << endl;
            }
        }
    }
    ++ (ipiv [col]);
    // see detailed comments in reference code for pivot bookkeeping scheme
    if (row != col)
    {
        for (l = 0; l <= 5; l++) swap (& mass_copy      [row][l],
                                         & mass_copy      [col][l]);
        for (l = 0; l <= 5; l++) swap (& mass_inverse [row][l],
                                         & mass_inverse [col][l]);
    }
    indxr [i] = row; // we are now ready to divide pivot row by pivot element
    indxc [i] = col; //      which is located at [row, col]
    if (mass_copy [col][col] == 0.0)
        cout << "invert error, singular matrix" << endl;

    pivinv = 1.0 / mass_copy [col][col];
    mass_copy [col][col] = 1.0;

    for (l = 0; l <= 5; l++) mass_copy [col][l] *= pivinv;
    for (l = 0; l <= 5; l++) mass_inverse [col][l] *= pivinv;

    for (ll = 0; ll <= 5; ll++) // next we reduce the rows
    {
        if (ll != col) // except for the pivot row, of course
        {
            dummy = mass_copy [ll][col];
            mass_copy [ll][col] = 0.0;
            for (l = 0; l <= 5; l++)
                mass_copy [ll][l] -= mass_copy [col][l] * dummy;

            for (l = 0; l <= 5; l++)
                mass_inverse [ll][l] -= mass_inverse [col][l] * dummy;
        }
    }
}
// we now unscramble the columns by interchanging in reverse order
for (l = 5; l >= 0; l--)
{
    if (indxr [l] != indxc [l])
    {
        for (k = 0; k <= 5; k++)
        {
            swap (& mass_copy [k][indxr [l]], & mass_copy [k][indxc [l]]);
        }
    }
}
}

```

```

//-----//
void UUVBody:: test_invert_matrix ()
{
    int i, j;

    calculate_mass_matrix ();

    cout << "Original mass matrix:" << endl;
    print_matrix6x6 (mass);

    invert_mass_matrix ();

    cout << endl;
    cout << "Inverted mass matrix:" << endl;
    print_matrix6x6 (mass_inverse);

    for (i = 0; i <= 5; i++)
    {
        for (j = 0; j <= 5; j++)
        {
            mass [i][j] = mass_inverse [i][j];
        }
    }
    invert_mass_matrix ();

    cout << endl;
    cout << "Double invert_mass_matrix () should get back to "
        << "original mass matrix:" << endl;

    print_matrix6x6 (mass_inverse);

    calculate_mass_matrix (); // restore
    invert_mass_matrix ();
}
//-----//

void UUVBody:: calculate_mass_matrix ()
{
#define UDOT      0           // matrix indices
#define VDOT      1
#define WDOT      2
#define PDOT      3
#define QDOT      4
#define RDOT      5
#define SURGE     0
#define SWAY      1
#define HEAVE     2
#define ROLL      3
#define PITCH     4
#define YAW       5

    mass [SURGE][UDOT] = m          - 0.5 * rho * L*L*L          * X_u_dot;
    mass [SURGE][VDOT] = 0.0;
    mass [SURGE][WDOT] = 0.0;
    mass [SURGE][PDOT] = 0.0;
    mass [SURGE][QDOT] = m * ( z_G);
    mass [SURGE][RDOT] = m * (-y_G);

    mass [SWAY ][UDOT] = 0.0;
    mass [SWAY ][VDOT] = m          - 0.5 * rho * L*L*L          * Y_v_dot;
    mass [SWAY ][WDOT] = 0.0;
    mass [SWAY ][PDOT] = m * (-z_G) - 0.5 * rho * L*L*L*L        * Y_p_dot;
    mass [SWAY ][QDOT] = 0.0;
    mass [SWAY ][RDOT] = m * ( x_G) - 0.5 * rho * L*L*L*L        * Y_r_dot;

    mass [HEAVE][UDOT] = 0.0;

```

```

mass [HEAVE] [VDOT] = 0.0;
mass [HEAVE] [WDOT] = m * (-0.5 * rho * L*L*L * Z_w_dot;
mass [HEAVE] [PDOT] = m * ( y_G);
mass [HEAVE] [QDOT] = m * (-x_G) - 0.5 * rho * L*L*L*L * Z_q_dot;
mass [HEAVE] [RDOT] = 0.0;

mass [ROLL ] [UDOT] = 0.0;
mass [ROLL ] [VDOT] = m * (-z_G) - 0.5 * rho * L*L*L*L * K_v_dot;
mass [ROLL ] [WDOT] = m * ( y_G);
mass [ROLL ] [PDOT] = I_x * (-0.5 * rho * L*L*L*L*L * K_p_dot;
mass [ROLL ] [QDOT] = -I_xy;
mass [ROLL ] [RDOT] = -I_xz - 0.5 * rho * L*L*L*L*L * K_r_dot;

mass [PITCH] [UDOT] = m * ( z_G);
mass [PITCH] [VDOT] = 0.0;
mass [PITCH] [WDOT] = m * (-x_G) - 0.5 * rho * L*L*L*L * M_w_dot;
mass [PITCH] [PDOT] = -I_xy;
mass [PITCH] [QDOT] = I_y * (-0.5 * rho * L*L*L*L*L * M_q_dot;
mass [PITCH] [RDOT] = -I_yz;

mass [YAW ] [UDOT] = m * (-y_G);
mass [YAW ] [VDOT] = m * ( x_G) - 0.5 * rho * L*L*L*L * N_v_dot;
mass [YAW ] [WDOT] = 0.0;
mass [YAW ] [PDOT] = -I_xz - 0.5 * rho * L*L*L*L*L * N_p_dot;
mass [YAW ] [QDOT] = -I_yz;
mass [YAW ] [RDOT] = I_z * (-0.5 * rho * L*L*L*L*L * N_r_dot;

}

//-----//

void AUVBody:: integrate_equations_of_motion ()
{
    current_uuv_time = AUV_time;

    double dt = current_uuv_time - time_of_posture_value ();

    if (dt < 0.0) // mission clock was reset, rezero the dynamics model
    {
        current_uuv_time = AUV_time;
        set_time_of_posture (AUV_time);
        set_velocities (0.0, 0.0, 0.0, 0.0, 0.0, 0.0);
        set_accelerations (0.0, 0.0, 0.0, 0.0, 0.0, 0.0);
        dt = 0.0;
        U = 0.0;
        V = 0.0;
        W = 0.0;
        P = 0.0;
        Q = 0.0;
        R = 0.0;
    }

    double rho2 = rho / 2.0;
    double L2 = L * L;
    double L3 = L * L * L;
    double L4 = L * L * L * L;
    double L5 = L * L * L * L * L;

    // note that sign is not preserved in the following squared variables
    // in order to present consistent naming with Healey reference paper.
    // To preserve sign, use (U * fabs (U)) etc.
    double P2 = P * P;
    double Q2 = Q * Q;
    double R2 = R * R;
    double U2 = U * U;
    double V2 = V * V;
    double W2 = W * W;

```

```

// calculate world coordinate posture rates, use holding variables for speed

double PHI      = phi_value  ();
double THETA    = theta_value ();
double PSI      = psi_value  ();

double sinPHI   = sin (   PHI );
double cosPHI   = cos (   PHI );
double sinTHETA = sin ( THETA );
double cosTHETA = cos ( THETA );
double sinPSI   = sin (   PSI );
double cosPSI   = cos (   PSI );

// double EPSILON = epsilon (); // no longer used in revised model

double delta_planes_stern = AUV_delta_planes;
double delta_planes_bow   = - AUV_delta_planes;

double delta_rudder_stern = AUV_delta_rudder;
double delta_rudder_bow   = - AUV_delta_rudder;

// integrate drag forces over the vehicle - - - - -
double sway_integral = 0.0;
double heave_integral = 0.0;
double pitch_integral = 0.0;
double yaw_integral = 0.0;

double dx, U_cf_x;

for (int x_index = 0; x_index < 14; x_index++) // longitudinal centerline
{
    dx = fabs (xx [x_index] - xx [x_index + 1]);

    U_cf_x = sqrt ( square (V + xx [x_index] * R)
                  + square (W - xx [x_index] * Q));

    if (U_cf_x > 1.0E-6) // arbitrary small non-0 minimum
    {
        sway_integral += rho2 * ( C_dy * hh [x_index]
                                * square ((V + xx [x_index] * R))
                                + C_dz * bb [x_index]
                                * square ((W - xx [x_index] * Q)))
                        * (V + xx [x_index] * R) * dx / U_cf_x;

        heave_integral += rho2 * ( C_dy * hh [x_index]
                                * square ((V + xx [x_index] * R))
                                + C_dz * bb [x_index]
                                * square ((W - xx [x_index] * Q)))
                        * (W - xx [x_index] * Q) * dx / U_cf_x;

        pitch_integral += rho2 * ( C_dy * hh [x_index]
                                * square ((V + xx [x_index] * R))
                                + C_dz * bb [x_index]

```

```

        * square ((W - xx [x_index] * Q))
    * (W - xx [x_index] * Q)
    // ^ note sign correction
    * xx [x_index] * dx / U_cf_x;

    yaw_integral += rho2 * ( C_dy * hh [x_index]
        * square ((V + xx [x_index] * R))
        + C_dz * bb [x_index]
        * square ((W - xx [x_index] * Q)))
    * (V + xx [x_index] * R)
    * xx [x_index] * dx / U_cf_x;
}
if (TRACE)
{
    cout << "dx = " << dx << ", U_cf_x = " << U_cf_x
        << ", sway_integral = " << sway_integral << endl;

    cout << "dx = " << dx << ", U_cf_x = " << U_cf_x
        << ", heave_integral = " << heave_integral << endl;

    cout << "dx = " << dx << ", U_cf_x = " << U_cf_x
        << ", pitch_integral = " << pitch_integral << endl;

    cout << "dx = " << dx << ", U_cf_x = " << U_cf_x
        << ", yaw_integral = " << yaw_integral << endl;
}

/////////////////////////////////////////////////////////////////
// calculate Equations of Motion right-hand sides //
/////////////////////////////////////////////////////////////////

rns [SURGE] = // Surge Motion Equation right hand side -----//
    m * ((V * R) - (W * Q) + x_G * (Q2 + R2) - y_G * P*Q - z_G * P*R)
    + rho2 * L4 * ( X_pp * P2 + X_qq * Q2
        + X_rr * R2 + X_pr * P*R)
    + rho2 * L3 * ( X_wq * W*Q + X_vp * V*P + X_vr * V*R
        + U*Q * ( X_uq_delta_bow * delta_planes_bow
            + X_uq_delta_stern * delta_planes_stern)
        + U*R * ( X_ur_delta_rudder * delta_rudder_bow
            + X_ur_delta_rudder * delta_rudder_stern)
        )
    + rho2 * L2 * ( X_vv * V2 + X_ww * W2
        + U*V * ( X_uv_delta_rudder * delta_rudder_stern)
        + U*W * ( X_uw_delta_bow * delta_planes_bow
            + X_uw_delta_stern * delta_planes_stern)
        + U * fabs (U) * ( X_uu_delta_b_delta_b
            * delta_planes_bow

```

```

        * delta_planes_bow
        + X_uu_delta_s_delta_s
        * delta_planes_stern
        * delta_planes_stern

        + X_uu_delta_r_delta_r
        * delta_rudder_bow
        * delta_rudder_bow

        + X_uu_delta_r_delta_r
        * delta_rudder_stern
        * delta_rudder_stern)
    )

    - (Weight - Buoyancy) * sinTHETA

    // EPSILON terms have been removed due to revised equations of motion

    // + rho2 * L3 * X_qdsn * U*Q * delta_planes_stern * EPSILON
    // + rho2 * L2 * EPSILON * ( X_wdsn * U*W * delta_planes_stern
    //
    //
    // + X_dsdsn * U2 * delta_planes_stern
    // + X_dsdsn * U2 * delta_planes_stern)

    // X_propulsion surge force (derived using expressions in Healey paper)
    // note that speed_per_rpm is associated with work of two propellers

    + rho2 * L2 * C_d0 * square (speed_per_rpm)
        * 0.5 * ( AUV_port_rpm * fabs (AUV_port_rpm)
            + AUV_stbd_rpm * fabs (AUV_stbd_rpm))

    // X_resistance surge drag (derived using expressions in Healey paper)

    - rho2 * L2 * C_d0 * U * fabs (U);

    ////////////////////////////////////////////////////////////////////

    if (TRACE: // Surge TRACE
    {
    cout << "surge term1=" << m * ((V * R) - (W * Q)
        + x_G * (Q2 + R2) - y_G * P*Q - z_G * P*R)<< endl;

    cout << "term2=" << + rho2 * L4 * ( X_pp * P2 + X_qq * Q2
        + X_rr * R2 + X_pr * P*R)
        << endl;

    cout << "term3=" << + rho2 * L3 * ( X_wq * W*Q + X_vp * V*P + X_vr * V*R
        + U*Q * ( X_uq_delta_bow * delta_planes_bow
            + X_uq_delta_stern * delta_planes_stern)
        + U*R * ( X_ur_delta_rudder * delta_rudder_stern
            + X_ur_delta_rudder * delta_rudder_bow)
        )
        << endl;

    cout << "term4=" << + rho2 * L2 * ( X_vv * V2 + X_ww * W2
        + U*V * ( X_uv_delta_rudder * delta_rudder_stern)
        + U*W * ( X_uw_delta_bow * delta_planes_bow
            + X_uw_delta_stern * delta_planes_stern)
        + U * fabs (U) * ( X_uu_delta_b_delta_b

```

```

        * delta_planes_bow
        * delta_planes_bow

    + X_uu_delta_s_delta_s
    * delta_planes_stern
    * delta_planes_stern

    + X_uu_delta_r_delta_r
    * delta_rudder_bow
    * delta_rudder_bow

    + X_uu_delta_r_delta_r
    * delta_rudder_stern
    * delta_rudder_stern)

    << endl;

cout << "term5=" << - (Weight - Buoyancy) * sinTHETA
    << endl;

cout << "term6,term7=" << "EPSILON terms, no longer used"
    << endl;

// cout << "term6=" << rho2 * L3 * X_qdsn * U*Q * delta_planes_stern
//      * EPSILON << endl;
//
// cout << "term7=" << rho2 * L2 * EPSILON * ( X_wdsn * U*W
//      * delta_planes_stern
//      + X_dsdsn * U2 * delta_planes_stern
//      * delta_planes_stern)
//      << endl;

cout << "term8=" << + rho2 * L2 * C_d0 * square (speed_per_rpm)
    * 0.5 * ( AUV_port_rpm * fabs (AUV_port_rpm)
    + AUV_stbd_rpm * fabs (AUV_stbd_rpm))

    << endl;

cout << "term9=" << - rho2 * L2 * C_d0 * U * fabs (U)
    << endl;
}

//////////////////////////////////////

rhs [SWAY ] = // Sway Motion Equation right hand side -----//

    m * (- (U * R) + (W * P) - x_G * (P * Q)
        + y_G * (P2 + R2)
        - z_G * (Q * R))

    + rho2 * L4 * ( Y_pq * P*Q + Y_qr * Q*R)
    + rho2 * L3 * ( Y_up * U*P + Y_ur * U*R
        + Y_vq * V*Q + Y_wp * W*P + Y_wr * W*R)
    + rho2 * L2 * ( Y_uv * U*V + Y_vw * V*W
        + U*fabs(U) * Y_uu_delta_rb * delta_rudder_bow
        + U*fabs(U) * Y_uu_delta_rs * delta_rudder_stern)

    - sway_integral

```

```

+ (Weight - Buoyancy) * cosTHETA * sinPHI
- (2.0 / (24.0 * 24.0)) // each thruster 2.0 lb per 24V signal squared
* ( AUV_bow_lateral * fabs (AUV_bow_lateral)
+ AUV_stern_lateral * fabs (AUV_stern_lateral));

////////////////////////////////////

if (TRACE) // Sway TRACE
{
cout << "sway term1=" << m * (- (U * R) + (W * P)
- x_G * (P * Q)
+ y_G * (P2 + R2)
- z_G * (Q * R))
<< endl;

cout << "term2=" << + rho2 * L4 * ( Y_pg * P*Q + Y_qr * Q*R)
<< endl;

cout << "term3=" << + rho2 * L3 * ( Y_up * U*P + Y_ur * U*R
+ Y_vq * V*Q + Y_wp * W*P + Y_wr * W*R)
<< endl;

cout << "term4=" << + rho2 * L2 * ( Y_uv * U*V + Y_vw * V*W
+ U*fabs(U) * Y_uu_delta_rb * delta_rudder_bow
+ U*fabs(U) * Y_uu_delta_rs * delta_rudder_stern)
<< endl;

cout << "term5=" << - sway_integral
<< endl;

cout << "term6=" << + (Weight - Buoyancy) * cosTHETA * sinPHI
<< endl;

cout << "term7=" << - (2.0 / (24.0 * 24.0))
// each thruster 2.0 lb per 24V signal squared
* ( AUV_bow_lateral * fabs (AUV_bow_lateral)
+ AUV_stern_lateral * fabs (AUV_stern_lateral))
<< endl;
}

////////////////////////////////////

rhs [HEAVE] = // Heave Motion Equation right hand side -----//
m * ( (U * Q) - (V * P) - x_G * (P * R) - y_G * (Q * R)
+ z_G * (P2 + Q2))
+ rho2 * L4 * ( Z_pp * P2 + Z_pr * P*R + Z_rr * R2)
+ rho2 * L3 * ( Z_uq * U*Q + Z_vp * V*P + Z_vr * V*R)
+ rho2 * L2 * ( Z_uw * U*W + Z_vv * V2
+ ( U*fabs(U) * Z_uu_delta_b * delta_planes_bow )
+ ( U*fabs(U) * Z_uu_delta_s * delta_planes_stern))

```

```

- heave_integral
+ (Weight - Buoyancy) * cosTHETA * cosPHI
// EPSILON terms have been removed due to revised equations of motion
// + rho2 * L3 *      Z_qn * U*Q * EPSILON
// + rho2 * L2 * (    Z_wn * U*W
//                + Z_dsn * U*fabs(U) * delta_planes_stern) * EPSILON
+ (2.0 / (24.0 * 24.0)) // each thruster 2.0 lb per 24V signal squared
    * ( AUV_bow_vertical * fabs (AUV_bow_vertical) +
      AUV_stern_vertical * fabs (AUV_stern_vertical));

// =====
if (TRACE) // Heave TRACE
{
cout << " * heave term1=" << m * ( (U * Q) - (V * P) - x_G * (P * R)
                                - y_G * (Q * R)
                                + z_G * (P2 + Q2))
    << endl;

cout << "term2=" << + rho2 * L4 * ( Z_pp * P2 + Z_pr * P*R
    + Z_rr * R2) << endl;

cout << "term3=" << + rho2 * L3 * ( Z_uq * U*Q + Z_vp * V*P
    + Z_vr * V*R) << endl;

cout << "term4=" << + rho2 * L2 * ( Z_uw * U*W + Z_vv * V2
    + ( U*fabs(U) * Z_uu_delta_b * delta_planes_bow )
    + ( U*fabs(U) * Z_uu_delta_s * delta_planes_stern))
    << endl;

cout << "term5=" << - heave_integral
    << endl;

cout << "term6=" << + (Weight - Buoyancy) * cosTHETA * cosPHI
    << endl;

cout << "term7=" << "EPSILON terms, no longer used"
    << endl;

cout << "term8=" << + rho2 * L2 * ( Z_wn * U*W )
    << endl;

cout << "term9=" << + (2.0 / (24.0 * 24.0))
    // each thruster 2.0 lb per 24V signal squared
    * ( AUV_bow_vertical * fabs (AUV_bow_vertical) +
      AUV_stern_vertical * fabs (AUV_stern_vertical) )
    << endl;
}

// =====
rhs [ROLL] = // Roll Motion Equation right hand side -----//
- (I_z - I_y) * Q*R - I_xy * P*R + I_yz * (Q2 - R2) + I_xz * P*Q
- m * ( y_G * (-U*Q + V*P) - z_G * (U*R - W*P))
+ rho2 * L5 * ( K_pq * P*Q + K_qr * Q*R

```

```

        + K_pp * P * fabs(P)
        + K_p * P ) // hovering roll drag
+ rho2 * L4 * ( K_up * fabs(U)*P + K_ur * U*R + K_vq * V*Q
        + K_wp * W*P + K_wr * W*R)
+ rho2 * L3 * ( K_uv * U*V + K_vw * V*W
        - U*fabs(U) * 0.5 * ( K_uu_planes * delta_planes_bow
        + K_uu_planes * delta_planes_stern))
// expected: opposed plane directions ^ cause negation & cancellation
+ (y_G * Weight - y_B * Buoyancy) * cosTHETA * cosPHI
- (z_G * Weight - z_B * Buoyancy) * cosTHETA * sinPHI;
// EPSILON terms have been removed due to revised equations of motion
// + rho2 * L4 * K_pn * U*P * EPSILON
+ rho2 * L3 * U*fabs(U) * K_prop; // oversimplified, in error
////////////////////////////////////
if (TRACE) // Roll TRACE
{
cout << "roll term1=" << - (I_z - I_y) * Q*R - I_xy * P*R + I_yz * (Q2 - R2)
        + I_xz * P*Q
        << endl;

cout << "term2=" << - m * ( y_G * ( -U*Q + V*P) - z_G * ( U*R - W*P))
        << endl;

cout << "term3=" << + rho2 * L5 * ( K_pq * P*Q + K_qr * Q*R
        + K_pp * P * fabs(P)
        + K_p * P ) // hovering roll drag
        << endl;

cout << "term4=" << + rho2 * L4 * ( K_up * fabs(U)*P + K_ur * U*R
        + K_vq * V*Q + K_wp * W*P + K_wr * W*R)
        << endl;

cout << "term5=" << + rho2 * L3 * ( K_uv * U*V + K_vw * V*W
        - U*fabs(U) * 0.5 * ( K_uu_planes * delta_planes_bow
        + K_uu_planes * delta_planes_stern))
        // expected: opposed plane directions ^ cause negation & cancellation
        << endl;

cout << "term6=" << + (y_G * Weight - y_B * Buoyancy) * cosTHETA * cosPHI
        << endl;

cout << "term7=" << - (z_G * Weight - z_B * Buoyancy) * cosTHETA * sinPHI
        << endl;

cout << "term8,term9=" << "EPSILON terms, no longer used"
        << endl;

// cout << "term8=" << + rho2 * L4 * K_pn * U*P * EPSILON
// << endl;

// cout << "term9=" << + rho2 * L3 * U*fabs(U) * K_prop
// << endl;
}

```

```

////////////////////////////////////
rhs [PITCH] = // Pitch Motion Equation right hand side -----//
- (I_x - I_z) * P*R + I_xy * Q*R - I_yz * P*Q - I_xz * (P2 - R2)
+ m * ( x_G * ( -U*Q + V*P) - z_G * ( - V*R + W*Q))
+ rho2 * L5 * ( M_pp * P2 + M_pr * P*R + M_rr * R*fabs (R)
               + M_q * Q
               + M_qq * Q * fabs(Q)) // hovering pitch drag
+ rho2 * L4 * ( M_uq * U*Q + M_vp * V*P + M_vr * V*R)
+ rho2 * L3 * ( M_uw * U*W + M_vv * V2
               + U*fabs(U) * ( M_uu_delta_bow * delta_planes_bow
                             + M_uu_delta_stern * delta_planes_stern))
+ pitch_integral // note sign corrections to Healey pitch_integral
- (x_G * Weight - x_B * Buoyancy) * cosTHETA * cosPHI
- (z_G * Weight - z_B * Buoyancy) * sinTHETA
+ (2.0 / (24.0 * 24.0)) // each thruster 2.0 lb per 24V signal squared
                        // multiplied by respective moment arms
                        // x_bow_vertical (+), x_stern_vert (-)
* ( (AUV_bow_vertical * fabs (AUV_bow_vertical) * x_bow_vertical)
    + (AUV_stern_vertical * fabs (AUV_stern_vertical) * x_stern_vertical));
// EPSILON terms have been removed due to revised equations of motion
// + rho2 * L4 * M_qn * U*Q * EPSILON
// + rho2 * L3 * (M_wn * U*W + M_dsn * U*fabs(U) * delta_planes_stern)
// * EPSILON;

////////////////////////////////////

if (TRACE) // Pitch TRACE
{
cout << "pitch term1=" << - (I_x - I_z) * P*R + I_xy * Q*R - I_yz * P*Q
      - I_xz * (P2 - R2) << endl;

cout << "term2=" << + m * ( x_G * ( -U*Q + V*P) - z_G * ( - V*R + W*Q))
      << endl;

cout << "term3=" << + rho2 * L5 * ( M_pp * P2 + M_pr * P*R + M_rr
      * R*fabs (R)
      + M_q * Q
      + M_qq * Q * fabs(Q)) // hovering pitch drag
      << endl;

cout << "term4=" << + rho2 * L4 * ( M_uq * U*Q + M_vp * V*P + M_vr * V*R)
      << endl;

cout << "term5=" << + rho2 * L3 * ( M_uw * U*W + M_vv * V2
      + U*fabs(U) * ( M_uu_delta_bow * delta_planes_bow
                    + M_uu_delta_stern * delta_planes_stern))
      << endl;

cout << "term6=" << + pitch_integral
      << endl;

cout << "term7=" << - (x_G * Weight - x_B * Buoyancy) * cosTHETA * cosPHI

```

```

    << endl;

cout << "term8=" << - (z_G * Weight - z_B * Buoyancy) * sinTHETA
    << endl;

cout << "term9=" << + (2.0 / (24.0 * 24.0))
    // each thruster 2.0 lb per 24V signal squared
    // multiplied by respective moment arms
    // x_bow_vertical (+). x_stern_vert (-)
    * ( (AUV_bow_vertical * fabs (AUV_bow_vertical) * x_bow_vertical)
        + (AUV_stern_vertical * fabs (AUV_stern_vertical) * x_stern_vertical))
    << endl;

cout << "term10,term11=" << "EPSILON terms, no longer used"
    << endl;

// cout << "term10=" << + rho2 * L4 * M_qn * U*Q * EPSILON
// << endl;

// cout << "term11=" << + rho2 * L3 * (M_wn * U*W + M_dsn * U*fabs(U)
//                                     * delta_planes_stern)
//                                     * EPSILON
// << endl;
//

/////////////////////////////////////////////////////////////////

rhs [YAW ] = // Yaw Motion Equation right hand side -----//

- (I_y - I_x) * P*Q + I_xy * (P2 - Q2) + I_yz * P*R - I_xz * Q*R
- m * ( x_G * ( U*R - W*P) - y_G * ( - V*R + W*Q))
+ rho2 * L5 * ( N_pq * P*Q + N_qr * Q*R
    + N_r * R
    + N_rr * R * fabs (R)) // hovering yaw drag
+ rho2 * L4 * ( N_up * U*P + N_ur * U*R + N_vq * V*Q
    + N_wp * W*P + N_wr * W*R)
+ rho2 * L3 * ( N_uv * U*V + N_vw * V*W
    + U*fabs(U) * N_uu_delta_rb * delta_rudder_bow
    - U*fabs(U) * N_uu_delta_rs * delta_rudder_stern)

- yaw_integral
+ (x_G * Weight - x_B * Buoyancy) * cosTHETA * sinPHI
+ (y_G * Weight - y_B * Buoyancy) * sinTHETA
- (2.0 / (24.0 * 24.0)) // each thruster 2.0 lb per 24V signal squared
    // multiplied by respective moment arms
    * ( (AUV_bow_lateral * fabs (AUV_bow_lateral) * x_bow_lateral )
        + (AUV_stern_lateral * fabs (AUV_stern_lateral) * x_stern_lateral ))
- rho2 * L2 * C_d0
    * ( square (speed_per_rpm) * 0.5 // propeller yaw
    * ( AUV_port_rpm * fabs(AUV_port_rpm) * y_port_propeller
        + AUV_stbd_rpm * fabs(AUV_stbd_rpm) * y_stbd_propeller)

```

```

- U * fabs(U));

/////////////////////////////////////////////////////////////////
if (TRACE) // Yaw TRACE
{
cout << "yaw term1=" << - (I_y - I_x) * P*Q + I_xy * (P2 - Q2)
+ I_yz * P*R - I_xz * Q*R
<< endl;

cout << "term2=" << - m * ( x_G * ( U*R - W*P) - y_G * ( - V*R + W*Q))
<< endl;

cout << "term3=" << + rho2 * L5 * ( N_pq * P*Q + N_qr * Q*R
+ N_r * R
+ N_rr * R * fabs (R)) // hovering yaw drag
<< endl;

cout << "term4=" << + rho2 * L4 * ( N_up * U*P + N_ur * U*R + N_vq * V*Q
+ N_wp * W*P + N_wr * W*R)
<< endl;

cout << "term5=" << + rho2 * L3 * ( N_uv * U*V + N_vw * V*W
+ U*fabs(U) * N_uu_delta_rb * delta_rudder_bow
- U*fabs(U) * N_uu_delta_rs * delta_rudder_stern)
<< endl;

cout << "term6=" << - yaw_integral
<< endl;

cout << "term7=" << + (x_G * Weight - x_B * Buoyancy) * cosTHETA * sinPHI
<< endl;

cout << "term8=" << + (y_G * Weight - y_B * Buoyancy) * sinTHETA
<< endl;

cout << "term9=" << - (2.0 / (24.0 * 24.0))
// each thruster 2.0 lb per 24V signal squared
// multiplied by respective moment arms
* ( (AUV_bow_lateral * fabs (AUV_bow_lateral) * x_bow_lateral )
+(AUV_stern_lateral * fabs (AUV_stern_lateral) * x_stern_lateral ))
<< endl;

cout << "term10=" << - rho2 * L2 * C_d0
* ( square (speed_per_rpm) * 0.5 // propeller yaw
* ( AUV_port_rpm * fabs(AUV_port_rpm) * y_port_propeller
+ AUV_stbd_rpm * fabs(AUV_stbd_rpm) * y_stbd_propeller)
- U * fabs(U))
<< endl;
}

/////////////////////////////////////////////////////////////////

// debug:

if (TRACE)
{
cout << " SURGE = " << SURGE << endl;
cout << " SWAY = " << SWAY << endl;
}

```

```

cout << "    HEAVE  = " <<    HEAVE << endl;
cout << "    ROLL   = " <<    ROLL  << endl;
cout << "    PITCH  = " <<    PITCH << endl;
cout << "    YAW    = " <<    YAW   << endl;

cout << "rhs [SURGE] = " << rhs [SURGE] << endl;
cout << "rhs [SWAY ] = " << rhs [SWAY ] << endl;
cout << "rhs [HEAVE] = " << rhs [HEAVE] << endl;
cout << "rhs [ROLL ] = " << rhs [ROLL ] << endl;
cout << "rhs [PITCH] = " << rhs [PITCH] << endl;
cout << "rhs [YAW ] = " << rhs [YAW ] << endl;

// cout << "mass_inverse:" << endl;  print_matrix6x6 (mass_inverse);

cout << "velocities:    <" << U << ", " << V << ", " << W << ", "
                        << P << ", " << Q << ", " << R << ">" << endl;

cout << "RHS:          ";      print_matrix6 (rhs);

// rhs [SURGE] = 0.0;
// rhs [SWAY ] = 0.0;
// rhs [HEAVE] = 0.0;
// rhs [ROLL ] = 0.0;
// rhs [PITCH] = 0.0;
// rhs [YAW ] = 0.0;

////////////////////////////////////

// calculate new accelerations matrix using mass_inverse & rhs, print -----//
multiply6x6_6 (mass_inverse, rhs, new_acceleration);

if (TRACE)
{
    cout << "Accelerations: ";  print_matrix6 (new_acceleration);
}

// limit accelerations -----//

clamp(& new_acceleration [SURGE], -5.0, 5.0, "new_acceleration [SURGE]");
clamp(& new_acceleration [SWAY ], -5.0, 5.0, "new_acceleration [SWAY ]");
clamp(& new_acceleration [HEAVE], -5.0, 5.0, "new_acceleration [HEAVE]");

clamp(& new_acceleration [ROLL ], -5.0, 5.0, "new_acceleration [ROLL ]");
clamp(& new_acceleration [PITCH], -5.0, 5.0, "new_acceleration [PITCH]");
clamp(& new_acceleration [YAW ], -5.0, 5.0, "new_acceleration [YAW ]");

// find velocities by integrating averaged accelerations -----//
//      (Heun integration)

new_velocity [SURGE] = 0.5 * (u_dot + new_acceleration [SURGE]) * dt + U;
new_velocity [SWAY ] = 0.5 * (v_dot + new_acceleration [SWAY ]) * dt + V;
new_velocity [HEAVE] = 0.5 * (w_dot + new_acceleration [HEAVE]) * dt + W;
new_velocity [ROLL ] = 0.5 * (p_dot + new_acceleration [ROLL ]) * dt + P;
new_velocity [PITCH] = 0.5 * (q_dot + new_acceleration [PITCH]) * dt + Q;
new_velocity [YAW ] = 0.5 * (r_dot + new_acceleration [YAW ]) * dt + R;

// find velocities by integrating instantaneous accelerations
//      (this method is less accurate and is not used, although at small
//      timesteps the difference is negligible)
//      (Euler integration)

// new_velocity [SURGE] = (new_acceleration [SURGE]) * dt + U;
// new_velocity [SWAY ] = (new_acceleration [SWAY ]) * dt + V;

```

```

// new_velocity [HEAVE] = (new_acceleration [HEAVE]) * dt + W;
// new_velocity [ROLL ] = (new_acceleration [ROLL ]) * dt + P;
// new_velocity [PITCH] = (new_acceleration [PITCH]) * dt + Q;
// new_velocity [YAW  ] = (new_acceleration [YAW  ]) * dt + R;

// note that surge velocity may be negative under to model constraints
// but this is a problem so it is clamped to be non-negative
clamp (& new_velocity [SURGE], -3.0, 3.0, "new_velocity [SURGE] velocity");
// 3.0 is set arbitrarily high

// update UUVBody state accelerations to newly-calculated values -----//
u_dot = new_acceleration [SURGE];
v_dot = new_acceleration [SWAY ];
w_dot = new_acceleration [HEAVE];
p_dot = new_acceleration [ROLL ];
q_dot = new_acceleration [PITCH];
r_dot = new_acceleration [YAW  ];

// calculate world coordinate system linear & angular velocities -----//
// see Cooke Figure 10 for corrections to Healey equations for x/y/z_dot:
// also Healey course notes eqn (26) and Frank-McGhee corrected paper (A.8)
x_dot = AUV_oceancurrent_u
        + U * cos (PSI) * cos (THETA)
        + V * (cos (PSI) * sin (THETA) * sin (PHI) - sin (PSI) * cos (PHI))
        + W * (cos (PSI) * sin (THETA) * cos (PHI) + sin (PSI) * sin (PHI));
y_dot = AUV_oceancurrent_v
        + U * sin (PSI) * cos (THETA)
        + V * (sin (PSI) * sin (THETA) * sin (PHI) + cos (PSI) * cos (PHI))
        + W * (sin (PSI) * sin (THETA) * cos (PHI) - cos (PSI) * sin (PHI));
z_dot = AUV_oceancurrent_w
        - U * sin (THETA)
        + V * cos (THETA) * sin (PHI)
        + W * cos (THETA) * cos (PHI);

phi_dot  = P + Q * sin (PHI) * tan (THETA)
          + R * cos (PHI) * tan (THETA);
theta_dot =    Q * cos (PHI)
              - R * sin (PHI);

if (cos (THETA) == 0.0)
{
    cout << "UUVBody::integrate_equations_of_motion (): " << endl;
    cout << "    cos (THETA) == 0.0 so psi_dot set equal to zero." << endl;
    psi_dot = 0.0;
}
else psi_dot = (Q * sin (PHI) + R * cos (PHI)) / cos (THETA);

```

```

Vector3D linear_rates = Vector3D (x_dot, y_dot, z_dot);
if (TRACE)
{
    cout << endl;
    cout << "<x_dot, y_dot, z_dot> = " << linear_rates << endl;
    cout << "          magnitude = " << linear_rates.magnitude ()
        << endl;
}

Vector3D euler_rates = Vector3D (phi_dot, theta_dot, psi_dot);
if (TRACE)
{
    cout << "<phi_dot, theta_dot, psi_dot> = " << euler_rates << endl;
    cout << "          magnitude = " << euler_rates.magnitude ()
        << endl;
}

// calculate world coordinate system homogenous transform matrix -----//

Hmatrix Hincremental = Hmatrix (); // default initialization
Hincremental.set_posture ( P * dt, Q * dt, R * dt );
Hincremental.rotate ( PHI, THETA, PSI );
double w_x = Hincremental.phi_value ();
double w_y = Hincremental.theta_value ();
double w_z = Hincremental.psi_value ();

Vector3D world_rates = Vector3D (w_x, w_y, w_z);
if (TRACE)
{
    cout << "<w_x, w_y, w_z> = " << world_rates << endl;
    cout << "          magnitude = " << world_rates.magnitude ()
        << endl;
}

Hmatrix Hrevised1 = Hmatrix (); // default initialization
Hrevised1.incremental_rotation ( phi_dot, theta_dot, psi_dot, dt );
Hrevised1.incremental_translation ( U, V, W, dt );

Hmatrix Hproduct1 = Hprevious * Hrevised1;

Hmatrix Hrevised2 = Hmatrix ( x_dot * dt, y_dot * dt, z_dot * dt,
                             phi_dot * dt, theta_dot * dt, psi_dot * dt);

Hprevious = Hproduct1;

// translate and rotate and update time in RigidBody state -----//
// note world coordinate system is used by RigidBody:

set_angular_velocities (phi_dot, theta_dot, psi_dot);
set_linear_velocities ( x_dot, y_dot, z_dot);
set_time_of_posture (current_uuv_time);
update_Hmatrix (dt);

if (TRACE)
{
    cout << "incremental hmatrix = ";
    Hincremental.print_hmatrix ();
    cout << "revised1 hmatrix = ";
    Hrevised1.print_hmatrix ();
    cout << "revised2 hmatrix = ";
    Hrevised2.print_hmatrix ();
    cout << "product1 hmatrix = ";
}

```

```

Hproduct1.print_hmatrix ();

cout << "original hmatrix = ";
hmatrix.print_hmatrix ();

cout << "substituting product1 hmatrix" << endl;
hmatrix = Hproduct1;

// -----

// Save body-coordinate-system velocities for the next loop:

U = new_velocity [SURGE];
V = new_velocity [SWAY ];
W = new_velocity [HEAVE];
P = new_velocity [ROLL ];
Q = new_velocity [PITCH];
R = new_velocity [YAW  ];

// cout << "world U =" << U << ", x_dot    = " << x_dot    << endl;
// cout << "world V =" << V << ", y_dot    = " << y_dot    << endl;
// cout << "world W =" << W << ", z_dot    = " << z_dot    << endl;
// cout << "world P =" << P << ", phi_dot   = " << phi_dot   << endl;
// cout << "world Q =" << Q << ", theta_dot = " << theta_dot << endl;
// cout << "world R =" << R << ", psi_dot   = " << psi_dot   << endl;

// -----
// update all hydrodynamics-model-provided state variables in AUV_globals.h
// prior to retransmittal to AUV via AUVsocket

AUV_time      = current_uuv_time; // mission time

AUV_x         = x_value    (); // x   position in world coordinates
AUV_y         = y_value    (); // y   position in world coordinates
AUV_z         = z_value    (); // z   position in world coordinates
AUV_phi       = phi_value  (); // roll posture in world coordinates
AUV_theta     = theta_value (); // pitch posture in world coordinates
AUV_psi       = psi_value  (); // yaw  posture in world coordinates

AUV_u         = new_velocity [SURGE]; // surge linear velocity along x-axis
AUV_v         = new_velocity [SWAY ]; // sway linear velocity along y-axis
AUV_w         = new_velocity [HEAVE]; // heave linear velocity along x-axis
AUV_p         = new_velocity [ROLL ]; // roll angular velocity about x-axis
AUV_q         = new_velocity [PITCH]; // pitch angular velocity about y-axis
AUV_r         = new_velocity [YAW  ]; // yaw angular velocity about z-axis

AUV_u_dot     = u_dot;      // linear acceleration along x-axis
AUV_v_dot     = v_dot;      // linear acceleration along y-axis
AUV_w_dot     = w_dot;      // linear acceleration along x-axis
AUV_p_dot     = p_dot;      // angular acceleration about x-axis
AUV_q_dot     = q_dot;      // angular acceleration about y-axis
AUV_r_dot     = r_dot;      // angular acceleration about z-axis

AUV_x_dot     = x_dot;      // Euler velocity along North-axis
AUV_y_dot     = y_dot;      // Euler velocity along East-axis
AUV_z_dot     = z_dot;      // Euler velocity along Depth-axis
AUV_phi_dot   = phi_dot;    // Euler rotation rate about North-axis
AUV_theta_dot = theta_dot;   // Euler rotation rate about East-axis
AUV_psi_dot   = psi_dot;    // Euler rotation rate about Depth-axis
}

#undef UDOT
#undef VDOT
#undef WDOT
#undef PDOT
#undef QDOT

```

```
#undef RDOT
#undef SURGE
#undef SWAY
#undef HEAVE
#undef ROLL
#undef PITCH
#undef YAW
```

```
//-----//
```

```
#endif // UUVBODY_C
```

F. *AUVsocket.C* Communications with a Networked AUV

```

/*****
Program:          AUVsocket.C

Description:       socket from auv execution level to Irix auv virtual world
                   receives partial telemetry, returns full telemetry with
                   dynamics parameters added

                   AUVsocket.C is a function library used by UUVBody

                   AUVsocket also provides voice server interface

Revised:          28 October 94

Compilation:       unix> make AUVsocket

Original bases:   os9server.c, dynamics.c

References:       (1) (Gespac-provided) EVIRA EVLAN-11 Ethernet Data Link
                   Controller for the G64/G96 Bus/EVTCP Internet Package
                   technical manuals
                   (2) Internetworking with TCP/IP Volume I: Principles,
                   Protocols and Architectures, Douglas E. Comer,
                   Prentice Hall, Englewood Cliffs NJ, 1991
                   (3) Internetworking with TCP/IP Volume II: Design,
                   Implementation and Internals, Douglas E. Comer and
                   David L. Stevens, Prentice Hall, Englewood Cliffs NJ, 1991
                   (4) IRIX Network Programming Guide, Silicon Graphics Inc.
                   (5) An Advanced 4.3BSD Interprocess Communication Tutorial,
                   Samuel J. Leffler, Robert S. Fabry, William N. Joy,
                   Phil Lapsley, Steve Miller and Chris Torek, undated
                   (6) Real-Time Programming Tutorial, Bill Mannel, SGI Expo,
                   Silicon Graphics Inc., 23 May 93
                   (7) "Say..." Axel Belinfante's speech server at University
                   of Twente, Netherlands, which also uses Nick Ing-Simmons'
                   phoneme synthesizer 'rsynth':
                   http://utis179.cs.utwente.nl:8001/say/?

Status:           Tested satisfactorily

Future work:       Consider implementation as an inetd 'superserver' daemon or
                   just closing socket when done, reopening & waiting

                   Consider bounds diagnostic checking on values transferred
                   over socket

                   Fix type mismatch on signal () calls - very gnarly problem!

                   Comments and suggestions are welcome!
*/

/*****/

#ifndef AUVSOCKET_C
#define AUVSOCKET_C    /* prevent errors if multiple #includes present */
/*****/

#define _BSD_SIGNALS
#include <ctype.h>
#include <signal.h>
#include <stdio.h>
#include <sys/types.h>

```

```

#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <string.h>
#include <time.h>
#include <stdlib.h>
#include <unistd.h>

#include "AUVglobals.H" // global state vector
#include "Quaternion.C" // degrees/radians conversions

// extern "C" entries provide function compatibility with C++ compiler - - - - -
extern "C" {
    void bzero    (void *b, int length);
    void bcopy    (const void *src, void *dst, int length);
    int  strncmp  (const char *s1, const char *s2, size_t n);
    char *strcpy  (char *s1, const char *s2);
    char *strncat (char *s1, const char *s2, size_t n);

    // reference p. 434 Kelley & Pohl "A Book on C",
    //      /usr/include/sys/signal.h and /usr/include/signal.h
    // int (*signal(int, int (*)(int, ...)))(int, ...);
};

/*****
/* One stream socket is used with adequate throughput */
/* (although two could work, no performance improvement is expected) */

/* Be careful that you reserve these port numbers to prevent collisions */
/* from other processes requesting ports on your system: */

#define LISBRIDGE_TCP_PORT    2056 /* disbridge 1.3 program, server & client */
#define NPSNET_MCAST_PORT    3111 /* Mike Macedonia's multicast DIS 2.0.3 */

/* NPS Autonomous Underwater Vehicle (AUV) */
/* Underwater Virtual World (UVW) */

#define AUVSIM1_TCP_PORT_0    3210 /* os9sender <==> os9server test programs */
#define AUVSIM1_TCP_PORT_1    3211 /* auv execution level <==> virtual world */
#define AUVSIM1_TCP_PORT_2    3212 /* auv execution <==> tactical (networked) */
#define AUVSIM1_TCP_PORT_3    3213 /* port for future use */
#define AUVSIM1_TCP_PORT_4    3214 /* port for future use */
#define AUVSIM1_TCP_PORT_5    3215 /* port for future use */
#define AUVSIM1_TCP_PORT_6    3216 /* port for future use */
#define AUVSIM1_TCP_PORT_7    3217 /* port for future use */
#define AUVSIM1_TCP_PORT_8    3218 /* port for future use */
#define AUVSIM1_TCP_PORT_9    3219 /* port for future use */

#define SOCKET_QUEUE_SIZE    5 /* max allowed by TCP/IP */

#define AUVSIM_EXECUTION_LEVEL_HOST_NAME "auvsim1.or.nps.navy.mil"

*****/

/* function prototypes *****/

int  open_execution_level_socket    ();
int  shutdown_socket                (int signal_thrown);
int  read_from_execution_level_socket (); // returns -1 on failure

```

```

void    write_to_execution_level_socket    ();

double  normalize                         (double degs);
double  normalize2                       (double degs);

void    AUV_global_initialization         ();

/*****
/* global variable definitions *****/

static int      socket_descriptor,
                socket_accepted,
                socket_stream;

static int      socket_length = 255; /* max allowed packet size */

static int      bytes_received, bytes_read, bytes_written,
                bytes_left, bytes_sent;

static char      command_sent    [300],
                command_received [300],
                command_copy     [300],
                remote_host_name [60];

static int      shutdown_signal_received = FALSE;

static FILE      * checksoundfile;

static struct sockaddr_in server_address;

static struct hostent * server_entity;

static char      keyword [81];

static char      * ptr_index;
static char      * remote_buffer;

static int      state_variables_received;
static int      return_state_vector;
static char      www_execution_message_string [300];
static char      answer;

static int      socket_already_opened = FALSE;
static int      audio_enabled        = TRUE;

*****/

int open_execution_level_socket () /* Initialize communications blocks */
{
    if (socket_already_opened == TRUE)
    {
        if (TRACE)
        {
            cout << "open_execution_level_socket (): socket_already_opened,"
                << " returning" << endl;
        }
        return (-1);
    }
    else if (TRACE) cout << "open_execution_level_socket () starting" << endl;
/*****
/* Initialize both client & server *****/

/* Signal handlers for termination to override net_open () and net_close ()*/

```

```

/*    signal handlers.  Otherwise you are unable to ^C kill this program. */

#ifdef(sgi)
// signal (SIGHUP,  shutdown_socket);          /* hangup                */
// signal (SIGINT,  shutdown_socket);          /* interrupt character     */
// signal (SIGKILL, shutdown_socket);          /* kill signal from Unix  */
// signal (SIGPIPE, shutdown_socket);          /* broken pipe from other host */
// signal (SIGTERM, shutdown_socket);          /* software termination   */
#endif

/*****
/* Initialize server *****/

/* setup to listen for client to attempt connection */
{
    /* Server opens server port *****/

    /* Open TCP (Internet stream) in socket */
    if ( (socket_descriptor = socket (AF_INET, SOCK_STREAM, 0)) < 0 )
    {
        cout << "open_execution_level_socket () can't 'open' stream socket"
              << endl;
        return (-1);
    }
    else if (TRACE)
    {
        cout << "open_execution_level_socket () socket 'open' successful"
              << endl;
    }

    /* Bind local address so client can talk to server */
#ifdef(sgi)
    bzero ((void *) &server_address, sizeof (server_address));
#endif
    server_address.sin_family      = AF_INET;    /* Internet protocol family */

    /* make sure port is in network byte order */
    server_address.sin_addr.s_addr = htonl (INADDR_ANY);
    server_address.sin_port       = htons (AUVSIM1_TCP_PORT_1);

    if (bind (
        socket_descriptor,
        (struct sockaddr *) &server_address,
        sizeof (server_address)) < 0)
    {
        cout << "open_execution_level_socket () socket 'bind' unsuccessful"
              << endl;
        return (-1);
    }
    else if (TRACE)
    {
        cout << "open_execution_level_socket () socket 'bind' successful"
              << endl;
    }

    /* prepare socket queue for connection requests using listen */
    listen (socket_descriptor, SOCKET_QUEUE_SIZE);
    if (TRACE)
    {
        cout << "open_execution_level_socket () socket 'listen' complete ..."
              << endl;
    }

    /* Server 'accept' waits for client connections *****/
    if (TRACE)
    {

```

```

        cout << "open_execution_level_socket () socket waiting to 'accept' ..."
              << endl;
    }
    bytes_received = sizeof (socket_descriptor);
    while ((socket_accepted = accept ( socket_descriptor,
                                      &server_address,
                                      &bytes_received)) < 1)

        if (TRUE) /* blocking code */
        {
            cout << "open_execution_level_socket () socket "
                  << "'accept' unsuccessful, sleeping 1 second ..." << endl;
            sleep (1);
        }
    cout << "open_execution_level_socket () connection is open between "
          << "networks." << endl;

; /* end initialization */

socket_stream = socket_accepted; /* server */

socket_already_opened = TRUE;

if (TRACE)
{
    cout << "AUVsocket SERVER: socket_descriptor = " << socket_descriptor
          << endl;
    cout << "                                socket_accepted = " << socket_accepted
          << endl;
    cout << "                                socket_stream = " << socket_stream
          << endl;
}

return (TRUE);
}

/*****
/*****

int read_from_execution_level_socket () // using global variables state vector
{
    /* temporary hold variables */

    double  AUV_time_temp,
            AUV_x_temp,      AUV_y_temp,      AUV_z_temp,
            AUV_phi_temp,    AUV_theta_temp,   AUV_psi_temp,
            AUV_u_temp,      AUV_v_temp,       AUV_w_temp,
            AUV_p_temp,      AUV_q_temp,       AUV_r_temp,
            AUV_x_dot_temp,   AUV_y_dot_temp,   AUV_z_dot_temp,
            AUV_phi_dot_temp, AUV_theta_dot_temp, AUV_psi_dot_temp,
            AUV_delta_rudder_temp, AUV_delta_planes_temp,
            AUV_port_rpm_temp, AUV_stbd_rpm_temp,
            AUV_bow_vertical_temp, AUV_stern_vertical_temp,
            AUV_bow_lateral_temp, AUV_stern_lateral_temp,
            AUV_ST1000_range_temp, AUV_ST725_range_temp,
            AUV_ST1000_bearing_temp, AUV_ST725_bearing_temp,
            AUV_ST1000_strength_temp, AUV_ST725_strength_temp;
    int      start_index, offset, index;

    /*****
    /* Receiver block */
    /*****

    for (index = 0; index < 300; index++) /* uppercase */
        command_received [index] = (char) 0;

    /* listen to remote host, relay to local network/program */

```



```

        &AUV_u_temp,          &AUV_v_temp,          &AUV_w_temp,
        &AUV_p_temp,          &AUV_q_temp,          &AUV_r_temp,
        &AUV_x_dot_temp,      &AUV_y_dot_temp,      &AUV_z_dot_temp,
        &AUV_phi_dot_temp,    &AUV_theta_dot_temp,    &AUV_psi_dot_temp,
        &AUV_delta_rudder_temp, &AUV_delta_planes_temp,
        &AUV_port_rpm_temp,    &AUV_stbd_rpm_temp,
        &AUV_bow_vertical_temp, &AUV_stern_vertical_temp,
        &AUV_bow_lateral_temp, &AUV_stern_lateral_temp,
        &AUV_ST1000_bearing_temp, &AUV_ST1000_range_temp,
        &AUV_ST1000_strength_temp,
        &AUV_ST725_bearing_temp, &AUV_ST725_range_temp,
        &AUV_ST725_strength_temp);

for (index = 0; index < strlen (keyword); index++) /* uppercase */
    keyword [index] = toupper (keyword [index]);

if (TRACE) printf ("[AUVsocket keyword=%s]\n", keyword);

if (state_variables_received == 34) // transfer was OK so keep new values
{
    if (TRACE) printf ("[AUVsocket state_variables_received == 34]\n");

    return_state_vector = TRUE;
    AUV_time = AUV_time_temp;
    AUV_x = AUV_x_temp;
    AUV_y = AUV_y_temp;
    AUV_z = AUV_z_temp;
    AUV_phi = radians (AUV_phi_temp);
    AUV_theta = radians (AUV_theta_temp);
    AUV_psi = radians (AUV_psi_temp);
    AUV_u = AUV_u_temp;
    AUV_v = AUV_v_temp;
    AUV_w = AUV_w_temp;
    AUV_p = radians (AUV_p_temp);
    AUV_q = radians (AUV_q_temp);
    AUV_r = radians (AUV_r_temp);
    AUV_x_dot = AUV_x_dot_temp;
    AUV_y_dot = AUV_y_dot_temp;
    AUV_z_dot = AUV_z_dot_temp;
    AUV_phi_dot = radians (AUV_phi_dot_temp);
    AUV_theta_dot = radians (AUV_theta_dot_temp);
    AUV_psi_dot = radians (AUV_psi_dot_temp);
    AUV_delta_rudder = radians (AUV_delta_rudder_temp);
    AUV_delta_planes = radians (AUV_delta_planes_temp);
    AUV_port_rpm = AUV_port_rpm_temp;
    AUV_stbd_rpm = AUV_stbd_rpm_temp;
    AUV_bow_vertical = AUV_bow_vertical_temp;
    AUV_stern_vertical = AUV_stern_vertical_temp;
    AUV_bow_lateral = AUV_bow_lateral_temp;
    AUV_stern_lateral = AUV_stern_lateral_temp;
    AUV_ST1000_bearing = AUV_ST1000_bearing_temp;
    AUV_ST1000_range = AUV_ST1000_range_temp;
    AUV_ST1000_strength = AUV_ST1000_strength_temp;
    AUV_ST725_bearing = AUV_ST725_bearing_temp;
    AUV_ST725_range = AUV_ST725_range_temp;
    AUV_ST725_strength = AUV_ST725_strength_temp;
}
else /* a message was received instead of telemetry */
{
    if (TRACE) printf ("[AUVsocket non-telemetry received]\n");

    return_state_vector = FALSE;

    if (strcmp (keyword, "AUV_STATE") == 0)
    {
        printf (
            "Garbled telemetry record received !!! variables_received=%d\n%s\n",

```

```

        state_variables_received, command_received);
    fflush (stdout);
    return_state_vector = FALSE;
    TRACE = TRUE;
    cin.get (answer); // pause
    cout << endl;
}
else if (strcmp (keyword, "MAIL") == 0)      /* Send e-mail request */
{
    printf ("%s\n", command_received);
    system ("      command_received");
}
else if (strncmp (command_received, "KILL", 4) == 0)
    /* KILL prior to reloop*/
{
    if (TRACE) printf ("[AUVsocket KILL]\n");

    shutdown_socket (0);
    return_state_vector = -3;
}
else if (strcmp (keyword, "TIME") == 0)
{
    if (TRACE) printf ("[AUVsocket TIME]\n");

    state_variables_received = sscanf (command_received, "%s%lf",
                                       keyword,
                                       &AUV_time_temp);

    if (state_variables_received == 2) // transfer OK, keep new values
    {
        AUV_time = AUV_time_temp;
        return_state_vector = FALSE;
        printf ("%s\n", command_received);
    }
    else
    {
        printf ("a bad time command was received & ignored: %s",
               command_received);
        return_state_vector = FALSE;
    }
}
else if ((strcmp (keyword, "POSITION") == 0) ||
         (strcmp (keyword, "LOCATION") == 0) )
{
    if (TRACE) printf ("[AUVsocket POSITION]\n");

    state_variables_received = sscanf (command_received, "%s%lf%lf%lf",
                                       keyword, &AUV_x_temp,
                                       &AUV_y_temp, &AUV_z_temp);

    if (state_variables_received == 4) // transfer OK, keep new values
    {
        AUV_x = AUV_x_temp;
        AUV_y = AUV_y_temp;
        AUV_z = AUV_z_temp;
        return_state_vector = -4;
        printf ("%s\n", command_received);
    }
    else
    {
        printf ("a bad position was received & ignored: %s",
               command_received);
        return_state_vector = FALSE;
    }
}
else if ((strcmp (keyword, "ROTATION") == 0) ||

```

```

        (strcmp (keyword, "ORIENTATION") == 0))
    {
        state_variables_received = sscanf (command_received, "%s%lf%lf%lf",
                                           keyword, &AUV_phi_temp,
                                           &AUV_theta_temp, &AUV_psi_temp);

        if (state_variables_received == 4) // transfer OK, keep new values
        {
            AUV_phi = radians (AUV_phi_temp);
            AUV_theta = radians (AUV_theta_temp);
            AUV_psi = radians (AUV_psi_temp);
            return_state_vector = -4;
            printf ("%s\n", command_received);
        }
        else
        {
            printf ("a bad orientation was received & ignored: %s",
                    command_received);
            return_state_vector = FALSE;
        }
    }
else if (strncmp (command_received, "AUDIBLE", 7) == 0) /* enable sound */
{
    printf ("[AUVsocket AUDIBLE]\n");

    return_state_vector = FALSE;
    audio_enabled = TRUE;
    return (return_state_vector); /* duplicate command copy not spoken */
}
else if (strncmp (command_received, "SILENT", 6) == 0) /* disable sound */
{
    printf ("[AUVsocket SILENT]\n");

    return_state_vector = FALSE;
    audio_enabled = FALSE;
}

if ((strncmp (keyword, "AUV_STATE", 10) != 0) /* non-telemetry string */
    && (audio_enabled == TRUE))
{
    /******
    /* generate audio of non-telemetry line passed by execution level */
    /* Don Brutzman Naval Postgraduate School brutzman@nps.navy.mil */
    /******

    start_index = 0;
    offset = 0;
    strcpy (command_copy, "");

    /* leading blanks in query are stripped */
    for (index = 0; index <= strlen (command_received); index++)
    {
        if (command_received [index] == ' ') start_index = index + 1;
        else break;
    }
    /* clean up any extra stuff in the query string */
    if (command_received [strlen (command_received)] == '\n')
    command_received [strlen (command_received) ] = '\0';
    command_received [strlen (command_received)-1] = '\0';

    int linelength = strlen (command_received);
    command_received [linelength] = (char) 0;

    // printf (" command_received [linelength] = (%d)\n",
    //         command_received [linelength]);

    for (index = start_index; index <= linelength; index++)

```

```

        if      ((command_received [index] == ' ') &&
                  (command_received [index+1] == ' '))
            offset = offset - 1; // ignore multiple blanks
        else if ((command_received [index] == ' ') &&
                  (isdigit (command_received [index+1])))
        {
            command_copy [index - start_index + offset] = ',';
            // don't put minus before number, use comma instead
        }
        else if (command_received [index] == ' ')
            command_copy [index - start_index + offset] = '-';
        else if (command_received [index] == '\n')
        {
            command_copy [index - start_index + offset] = (char) 0;
            break;
        }
        else command_copy [index - start_index + offset] =
            tolower (command_received [index]);
    }
    printf (" Say...%s\n", command_received);
    if (TRACE) printf ("[Say...%s]\n", command_copy);

    /* build the remote query which will also save results as -object */

    strcpy (keyword, "speech/");
    strcat (keyword, command_copy);
    strcat (keyword, ".au");

    checksoundfile = fopen (keyword, "r");

    if (checksoundfile == NULL) /* file not previously retrieved-do so */
    {
        if (TRUE)
        {
            printf ("[%s not found, making remote query to \n", keyword);
            printf (" the Say.. audio server in Netherlands]\n");
        }
        sprintf (www_execution_message_string,
            "www -o speech/%s.au http://www.tios.cs.utwente.nl/say/?%s",
                command_copy, command_copy);
        if (TRACE) printf ("[%s]\n", www_execution_message_string);
        system (www_execution_message_string);
    }
    else
    {
        if (TRACE)
            printf ("[%s was found locally, no remote query required]\n",
                keyword);
        fclose (checksoundfile);
    }
    /* build string to play the audio file, then do so. */
    /* don't put sfplay in background or audio port may be unavailable */
    /* when the next audio message is sent */
    sprintf (www_execution_message_string, "sfplay speech/%s.au",
        command_copy);
    if (TRACE) printf ("[%s]\n", www_execution_message_string);
    system (www_execution_message_string);

    /******
    /* audio send complete *****/
    /******
}

} /* end processing a message */

```

```

    return (return_state_vector);

} /* end read_from_execution_level_socket () */

/*****
/*****

void write_to_execution_level_socket () // using global variables state vector
{
    sprintf (command_sent,
" uvw_state %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f
%5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %5.3f
%5.3f %5.3f %5.3f %5.3f %5.3f %5.3f %d %5.3f %5.3f \n",
        AUV_time, AUV_x, AUV_y, AUV_z,
        normalize2 (degrees (AUV_phi)),
        normalize2 (degrees (AUV_theta)),
        normalize (degrees (AUV_psi)),
        AUV_u, AUV_v, AUV_w,
        normalize2 (degrees (AUV_p)),
        normalize2 (degrees (AUV_q)),
        normalize2 (degrees (AUV_r)),
        AUV_x_dot, AUV_y_dot, AUV_z_dot,
        normalize2 (degrees (AUV_phi_dot)),
        normalize2 (degrees (AUV_theta_dot)),
        normalize2 (degrees (AUV_psi_dot)),
        normalize2 (degrees (AUV_delta_rudder)),
        normalize2 (degrees (AUV_delta_planes)),
        AUV_port_rpm, AUV_stbd_rpm,
        AUV_bow_vertical, AUV_stern_vertical,
        AUV_bow_lateral, AUV_stern_lateral,
        AUV_ST1000_bearing, AUV_ST1000_range, AUV_ST1000_strength,
        AUV_ST725_bearing, AUV_ST725_range, AUV_ST725_strength
    );

    if (TRACE) cout << command_sent << endl;

/*****
/* Sender block */
/*****

bytes_received = strlen (command_sent);

if (bytes_received < 0) /* copy failure */
{
    cout << "write_to_execution_level_socket () ";
    cout << "copy from command_received unsuccessful" << endl;
    shutdown_socket (0);
    return;
}

else if (bytes_received > socket_length)
{
    cout << "write_to_execution_level_socket () "
        << "send_telemetry_to_server error: " << endl;
    cout << "bytes_received too big for packet socket_length"
        << " [bytes_received=" << bytes_received
        << "] > [socket_length=" << socket_length << "]; "
        << "string truncated" << endl;
}

bytes_left = socket_length;
bytes_written = 0;
ptr_index = command_sent;

while ((bytes_left > 0) && (bytes_written >= 0)) /* write loop *****/
{
    bytes_sent = write (socket_stream, ptr_index, bytes_left);

```

```

        if (bytes_sent < 0) bytes_written = bytes_sent;
        else if (bytes_sent > 0)
        {
            bytes_left -= bytes_sent;
            bytes_written += bytes_sent;
            ptr_index += bytes_sent;
        }
        if (TRACE && (bytes_written != socket_length))
        {
            cout << "write_to_execution_level_socket () loop bytes sent = "
                << bytes_sent << endl;
        }
    }
    if (bytes_written < 0)
    {
        cout << "write_to_execution_level_socket () send failed, "
            << bytes_written << " bytes_written" << endl;
    }
    else if (TRACE)
    {
        cout << "write_to_execution_level_socket () total bytes sent = "
            << bytes_written << endl;
    }

    return;
} /* end write_to_execution_level_socket ();
*/

/*****
*****/

int shutdown_socket (int signal_thrown) /* Shutdown block */
{
    int close_result;

    if (TRACE)
        cout << "shutdown_socket (" << signal_thrown
            << ") shutdown in progress ..." << endl;

    shutdown_signal_received = TRUE;

    /* No need to send a message to other side that bridge is going down, */
    /* since SIGPIPE signal trigger may cause shutdown on other side */

    close_result = close (socket_stream);

    if (close_result == -1)
        cout << "shutdown_socket () close (socket_stream) failed" << endl;

    if (TRUE) cout << "shutdown_socket () complete" << endl;

    return (close_result);
} /* end shutdown_socket () */

/*****
*****/

double normalize (double degs) /* degrees input*/
{
    double result = degs;

    while (result < 0.0) result += 360.0;
    while (result >= 360.0) result -= 360.0;
}

```

```

    return result;
}
/*****
*****/

double normalize2 (double degs)    /* degrees input*/
{
    double result = degs;

    while (result <= -180.0) result += 360.0;
    while (result > 180.0) result -= 360.0;

    return result;
}
/*****
*****/

void AUV_global_initialization ()
{
    // Variable initialization performed separately to avoid compiler warnings - -

    AUV_time           = 0.0; // mission time
    AUV_delta_rudder   = 0.0; // positive is bow rudder _____
    AUV_delta_planes   = 0.0; // positive is bow planes _____
    AUV_port_rpm       = 0.0; // propellor revolutions per minute
    AUV_stbd_rpm       = 0.0; // propellor revolutions per minute

    AUV_bow_vertical   = 0.0; // thruster volts 24V = 3820 rpm no load
    AUV_stern_vertical = 0.0; // thruster volts 24V = 3820 rpm no load
    AUV_bow_lateral    = 0.0; // thruster volts 24V = 3820 rpm no load
    AUV_stern_lateral  = 0.0; // thruster volts 24V = 3820 rpm no load

    AUV_depth_cell     = 0.0; // pressure sensor, units are _____
    AUV_heading        = 0.0; // gyrocompass in degrees
    AUV_roll_angle     = 0.0; // matches inertial sensor onboard AUV
    AUV_pitch_angle    = 0.0; // matches inertial sensor onboard AUV
    AUV_roll_rate      = 0.0; // matches inertial sensor onboard AUV
    AUV_pitch_rate     = 0.0; // matches inertial sensor onboard AUV
    AUV_yaw_rate       = 0.0; // matches inertial sensor onboard AUV

    AUV_hour           = 0;    // internal AUV OS-9 system time, unused
    AUV_minute         = 0;
    AUV_second         = 0;

    // Hydrodynamics-model-provided state variables - - - - -

    AUV_x              = 0.0; // x    position in world coordinates
    AUV_y              = 0.0; // y    position in world coordinates
    AUV_z              = 0.0; // z    position in world coordinates
    AUV_phi            = 0.0; // roll posture in world coordinates
    AUV_theta          = 0.0; // pitch posture in world coordinates
    AUV_psi            = 0.0; // yaw  posture in world coordinates

    AUV_x_dot          = 0.0; //      Euler velocity along North-axis
    AUV_y_dot          = 0.0; //      Euler velocity along East-axis
    AUV_z_dot          = 0.0; //      Euler velocity along Depth-axis
    AUV_phi_dot        = 0.0; // Euler rotation rate about North-axis
    AUV_theta_dot      = 0.0; // Euler rotation rate about East-axis
    AUV_psi_dot        = 0.0; // Euler rotation rate about Depth-axis

    AUV_u              = 0.0; // surge linear velocity along x-axis
    AUV_v              = 0.0; // sway linear velocity along y-axis
    AUV_w              = 0.0; // heave linear velocity along z-axis
    AUV_p              = 0.0; // roll angular velocity about x-axis
    AUV_q              = 0.0; // pitch angular velocity about y-axis
    AUV_r              = 0.0; // yaw angular velocity about z-axis

```

```

AUV_u_dot      = 0.0; // linear acceleration along x-axis
AUV_v_dot      = 0.0; // linear acceleration along y-axis
AUV_w_dot      = 0.0; // linear acceleration along z-axis
AUV_p_dot      = 0.0; // angular acceleration about x-axis
AUV_q_dot      = 0.0; // angular acceleration about y-axis
AUV_r_dot      = 0.0; // angular acceleration about z-axis

AUV_oceancurrent_u = 0.0; // Ocean current rate along North-axis
AUV_oceancurrent_v = 0.0; // Ocean current rate along East-axis
AUV_oceancurrent_w = 0.0; // Ocean current rate along Depth-axis

// Prior time loop saved variables - - - - -

AUV_time_prior    = 0.0; // mission time

AUV_x_prior       = 0.0; // x position in world coordinates
AUV_y_prior       = 0.0; // y position in world coordinates
AUV_z_prior       = 0.0; // z position in world coordinates

AUV_phi_prior     = 0.0; // roll posture in world coordinates
AUV_theta_prior   = 0.0; // pitch posture in world coordinates
AUV_psi_prior     = 0.0; // yaw posture in world coordinates

// Sonar- & terrain-model-provided state variables - - - - -

AUV_ST1000_bearing = 0.0; // ST_1000 conical pencil beam bearing
AUV_ST1000_range   = 0.0; // ST_1000 conical pencil beam range
AUV_ST1000_strength = 0.0; // ST_1000 conical pencil beam strength

AUV_ST725_bearing  = 0.0; // ST_725 1 x 24 sector beam bearing
AUV_ST725_range    = 0.0; // ST_725 1 x 24 sector beam range
AUV_ST725_strength = 0.0; // ST_725 1 x 24 sector beam strength

#endif /* AUVSOCKET_C */

```

G. *DISNetworkedRigidBody.C* DIS Network Connections for a Rigid Body

```

/////////////////////////////////////////////////////////////////
/*
Program:          DISNetworkedRigidBody.C

Description:      DIS network interface for RigidBody model

Author:          Don Brutzman

Revised:         28 October 94

System:          Irix 5.2

Compiler:        ANSI C++

Compilation:      irix> make dynamics
                  irix> CC DISNetworkedRigidBody.C -lm -c -g +w

Original bases:  os9server.c, dynamics.c, DIS library test_it.c

References:      (1) IEEE Protocols for Distributed Interactive Simulation (DIS)
                  Applications version 2.0, Institute for Simulation and
                  Training, University of Central Florida, Orlando Florida,
                  28 May 1993.

                  (2) Macedonia, Michael, Zeswitz, Steven, and Locke, John,
                  Distributed Interactive Simulation (DIS) multicast
                  version 2.0.3, Naval Postgraduate School, February 94.

                  (3) Zeswitz, Steven, "NPSNET: Integration of Distributed
                  Interactive Simulation (DIS) Protocol for Communication
                  Architecture and Information Interchange." master's thesis,
                  Naval Postgraduate School, Monterey California, 28 May 1993.

Units:           Virtual world:  ft    ft/sec  radians  radians/sec
                  DIS PDUs:      m    m/sec  degrees  degrees/sec

Future work:

Advisors:        Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

*/
/////////////////////////////////////////////////////////////////

#ifndef DISNETWORKEDRIGIDBODY_C
#define DISNETWORKEDRIGIDBODY_C // prevent errors if multiple #includes present

#define METERS_PER_FT  0.3048
#define FT_PER_METERS  3.2808

#include "RigidBody.C"
#include "AUVsocket.C"
#include <string.h>
#include <bstring.h>
#include <time.h>

// DIS includes.  See Makefile for other DIS #include files; they must match.

#include "../DIS.mcast/h/disdefs.h"
#include "../DIS.mcast/h/appearance.h"

/////////////////////////////////////////////////////////////////

```

```

// DIS library function prototypes do not include parameter prototypes, thus
// needed ones are included here. Function definitions are located in
// /n/elsie/work3/macedoni/net/mcast/network/src
///////////////////////////////////////////////////////////////////

class DISNetworkedRigidBody : public RigidBody
{
private:
// member data fields

    double          time_of_last_PDU;

    int             DIS_port_open;

    EntityID        UUV_DIS_id;

    EntityType       UUV_DIS_type;

    EntityStatePDU * UUV_DIS_pdu;

    clock_t          current_clock,    // clock tick counter for current loop
                    initialclock,
                    previous_clock,
                    delta_clock;

    double           delta_time;

    int              PDU_skip_interval;

    // Multicast Defaults from
    // /n/elsie/work3/macedoni/net/mcast/network/utils/planes/planes.cc

    char  MULTICAST_PORT   [6];
    char  MULTICAST_GROUP  [20];
    char  port              [6];    // pointer to MULTICAST_PORT
    char  group             [20];    // MULTICAST_GROUP
    u_char ttl;              // time-to-live

public:
// member constructor and destructor functions

    DISNetworkedRigidBody          ();

    ~DISNetworkedRigidBody          () { /* null body */ }

// operators

    friend ostream& operator <<          (ostream& out,
                                           DISNetworkedRigidBody& nrb);

// inspection methods

    void          print_networkedrigidbody          () const;

    double        time_of_last_PDU_value            () const;

    int           DIS_port_open_value               () const;

    int           PDU_skip_interval_value           () const;

// modifying methods

    void          set_PDU_skip_interval            (const int new_value);

    int           DIS_net_open                     ();

```

```

int      DIS_net_write          ();
void     DIS_net_close          ();
void     DISNetworkedRigidBody_initialize ();
void     set_time_of_last_PDU    (const double new_time_of_last_PDU);
void     set_ttl                 (int      new_ttl);
void     set_group               (char * new_group);
void     set_port                (char * new_port);

};

//-----//
// constructor methods
//-----//

DISNetworkedRigidBody::DISNetworkedRigidBody () // default constructor
{
    PDU_skip_interval = 1;           // 1 tenth(s) of a second between PDUs

    RigidBody_initialize ();          // inherited method
    time_of_last_PDU = 0.0;
    DIS_port_open = FALSE;

    // initialize clock variables
    initialclock      = clock ();
    previous_clock    = clock ();

    // Multicast Defaults from
    // /n/elsie/work3/macedoni/net/mcast/network/utils/planes/planes.cc

    bzero (MULTICAST_PORT, 6);
    bzero (MULTICAST_GROUP, 20);
    strcpy (MULTICAST_PORT, "3111"); // 3111 npsnet 'standard' address
    strcpy (MULTICAST_GROUP, "224.2.121.93");

    bzero (port, 6);
    bzero (group, 20);
    strcpy (port, MULTICAST_PORT);
    strcpy (group, MULTICAST_GROUP);

    ttl = 16;           // multicast ttl=16 stays inside NPS
}
//-----//
// operators
//-----//

ostream& operator << (ostream& out, DISNetworkedRigidBody& nrb)
{
    nrb.print_rigidbody ();
    out << "time_of_last_PDU = " << nrb.time_of_last_PDU << endl;
    return (out);
}
//-----//
// inspection methods
//-----//

void DISNetworkedRigidBody::print_networkedrigidbody ()
const
{

```

```

    print_rigidbody ();
    cout << "time_of_last_PDU   = " << time_of_last_PDU << endl;
}
//-----//

double DISNetworkedRigidBody:: time_of_last_PDU_value ()
const
{
    return time_of_last_PDU;
}
//-----//

int DISNetworkedRigidBody:: DIS_port_open_value ()
const
{
    return DIS_port_open;
}
//-----//

int DISNetworkedRigidBody:: PDU_skip_interval_value ()
const
{
    return PDU_skip_interval;
}
//-----//
// modifying methods
//-----//

void DISNetworkedRigidBody:: set_PDU_skip_interval (const int new_value)
{
    if (PDU_skip_interval >= 1) PDU_skip_interval = new_value;
    else
    {
        PDU_skip_interval = 10;
        cout << "PDU_skip_interval must be >= 1, and has been set to 1." << endl;
    }

    return;
}
//-----//

int DISNetworkedRigidBody:: DIS_net_open () // Ref: macedonia include files
{
    int    exercise_id      = -1;
    int    coordinate_system = 0; // 0 = flat world, 1 = round world
    char * utm_file         = "";

    int result = FALSE;

    if (DIS_port_open == FALSE)
    {
        result = net_open (port, group, ttl,
                           exercise_id, coordinate_system, utm_file);

        // result = net_open (port, group, ttl); // old version

        if (result == FALSE)
        {
            DIS_port_open = FALSE;
            cout << "DIS_net_open_select () failed" << endl;
        }
        else
        {
            DIS_port_open = TRUE;
            // atexit (net_close); // ensure port is reclosed on exit.
        }
    }
}

```

```

else
{
    cout << "DIS_port_open == TRUE so DIS_net_open () not re-attempted."
    << endl;
    result = TRUE;
}
return result;
}
//-----//

int DISNetworkedRigidBody::DIS_net_write ()
{
    current_clock      = clock ();
    delta_clock        = current_clock - previous_clock;
    delta_time         = delta_clock / CLOCKS_PER_SEC;

    if (TRACE) cout << "DISNetworkedRigidBody::DIS_net_write:AUV_time = "
    << AUV_time;

    // do not write faster than one DIS PDU per PDU_skip_interval tenth-seconds
    // of AUV_time
    if ((int) (AUV_time * 10.0) % PDU_skip_interval != 0)
    {
        if (TRACE) cout << ", returning." << endl;
        return (TRUE);
    }
    else if (TRACE) cout << ", sending DIS PDU." << endl;

    previous_clock = current_clock;

    // see test_it.c ('client' program) in DIS library for examples:
    // /n/elsie/work3/macedoni/net/mcast/network/src/test_it.c

    UUV_DIS_id.address.site = SITE_ID_NPS; // DIS standard para 5.3.8.1.1

    UUV_DIS_id.address.host = (unsigned short) 1;
    UUV_DIS_id.entity      = (unsigned short) 1;

    // force the #define values to the right types
    UUV_DIS_type.entity_kind = (unsigned char) EntityKind_Platform;
    UUV_DIS_type.domain     = (unsigned char) Domain_Subsurface;
    UUV_DIS_type.country    = (unsigned short) USA;
    // not yet defined in DIS header file
    // UUV_DIS_type.category = (unsigned char) Category_ResearchMiscSub;
    UUV_DIS_type.subcategory = (unsigned char) 0;
    UUV_DIS_type.specific   = (unsigned char) 0;

    UUV_DIS_pdu = mallocEntityStatePDU();

    // fill in the parameters of an entity state PDU (most are listed in pdu.h)
    // this assumes there are no articulated parameters (add later) <<<<<

    // Note all units converted to SI when building PDU

    // DIS ID and Type
    UUV_DIS_pdu->entity_id      = UUV_DIS_id;
    UUV_DIS_pdu->entity_type    = UUV_DIS_type;
    UUV_DIS_pdu->force_id       = ForceID_White;
    UUV_DIS_pdu->alt_entity_type.extra = (Extra) 0x00; // unused extra parameter

    // Posture
    UUV_DIS_pdu->entity_location.x      = AUV_x * METERS_PER_FT;
    UUV_DIS_pdu->entity_location.y      = AUV_y * METERS_PER_FT;
    UUV_DIS_pdu->entity_location.z      = AUV_z * METERS_PER_FT;
    UUV_DIS_pdu->entity_orientation.psi = (int) degrees (AUV_psi) % 360;
    UUV_DIS_pdu->entity_orientation.theta = (int) degrees (AUV_theta) % 360;
    UUV_DIS_pdu->entity_orientation.phi  = (int) degrees (AUV_phi) % 360;

```

```

// Linear and angular velocities in body coordinates/meters by DIS standard
UUV_DIS_pdu->entity_velocity.x      = AUV_x_dot * METERS_PER_FT;
UUV_DIS_pdu->entity_velocity.y      = AUV_y_dot * METERS_PER_FT;
UUV_DIS_pdu->entity_velocity.z      = AUV_z_dot * METERS_PER_FT;

UUV_DIS_pdu->dead_reckon_params.angular_velocity [0] =
    (int) degrees (AUV_phi_dot) % 360;

UUV_DIS_pdu->dead_reckon_params.angular_velocity [1] =
    (int) degrees (AUV_theta_dot) % 360;

UUV_DIS_pdu->dead_reckon_params.angular_velocity [2] =
    (int) degrees (AUV_psi_dot) % 360;

// no explicit world coordinate accelerations are provided by dynamics model
UUV_DIS_pdu->dead_reckon_params.linear_accel [0] = 0.0;
UUV_DIS_pdu->dead_reckon_params.linear_accel [1] = 0.0;
UUV_DIS_pdu->dead_reckon_params.linear_accel [2] = 0.0;

// debug code:
// UUV_DIS_pdu->entity_velocity.x      = 0.0;
// UUV_DIS_pdu->entity_velocity.y      = 0.0;
// UUV_DIS_pdu->entity_velocity.z      = 0.0;
// UUV_DIS_pdu->dead_reckon_params.angular_velocity [0] = 0;
// UUV_DIS_pdu->dead_reckon_params.angular_velocity [1] = 0;
// UUV_DIS_pdu->dead_reckon_params.angular_velocity [2] = 0;

if (TRUE)
{
    cout << endl;
    cout << "DIS_net_write: time " << AUV_time << ": ";
    cout << "[";
    cout << UUV_DIS_pdu->entity_location.x      << ", ";
    cout << UUV_DIS_pdu->entity_location.y      << ", ";
    cout << UUV_DIS_pdu->entity_location.z      << ", ";
    cout << UUV_DIS_pdu->entity_orientation.phi << ", ";
    cout << UUV_DIS_pdu->entity_orientation.theta << ", ";
    cout << UUV_DIS_pdu->entity_orientation.psi << "]" << endl;
}

if (TRACE)
{
    cout << "World coordinate velocities: ";
    cout << "[";
    cout << UUV_DIS_pdu->entity_velocity.x      << ", ";
    cout << UUV_DIS_pdu->entity_velocity.y      << ", ";
    cout << UUV_DIS_pdu->entity_velocity.z      << ", ";
    cout << UUV_DIS_pdu->dead_reckon_params.angular_velocity [0] << ", ";
    cout << UUV_DIS_pdu->dead_reckon_params.angular_velocity [1] << ", ";
    cout << UUV_DIS_pdu->dead_reckon_params.angular_velocity [2] << "]"
    << endl;
}

if (TRACE)
{
    cout << "World coordinate accelerations: ";
    cout << "[";
    cout << UUV_DIS_pdu->dead_reckon_params.linear_accel [0] << ", ";
    cout << UUV_DIS_pdu->dead_reckon_params.linear_accel [1] << ", ";
    cout << UUV_DIS_pdu->dead_reckon_params.linear_accel [2] << "]" << endl;
}

// what we look like
UUV_DIS_pdu->entity_appearance = AppearanceSubSurf_SmallWake;
UUV_DIS_pdu->entity_marking.character_set = CharSet_ASCII;
strncpy ((char *) UUV_DIS_pdu->entity_marking.markings, "NPS AUV ",
    MARKINGS_LEN);

```

```

ArticulatParamsNode * APNptr;

// articulated parameters: rudders, planes, test with execution level rpm,
stbd rpm

// note that the function specification for attachArticulatParamsNode
// needed to be corrected to accept (char *) in file disdefs.h

if (APNptr = attachArticulatParamsNode ((char *) UUV_DIS_pdu,
                                         EntityStatePDU_Type))
{
    // Successful attach, fill in data. See DIS standard paragraph 5.3.3
    APNptr->articulat_params.change = TRUE; // always active
    APNptr->articulat_params.ID = 0; // articulated parameter #
    APNptr->articulat_params.parameter_value [0] // auv time, even seconds
        = (unsigned short) ((int) AUV_time % 600);
    APNptr->articulat_params.parameter_value [1] // auv time tenths of seconds
        = (unsigned short) (AUV_time * 10) % 10;
    APNptr->articulat_params.parameter_value [2]
        = (signed short) ((int) degrees (AUV_delta_rudder)
                           % 360);
    APNptr->articulat_params.parameter_value [3]
        = (signed short) ((int) degrees (AUV_delta_planes)
                           % 360);
    APNptr->articulat_params.parameter_value [4]
        = (signed short) ((int) AUV_port_rpm / 10);
    APNptr->articulat_params.parameter_value [5]
        = (signed short) ((int) fabs (AUV_port_rpm) % 10);
    APNptr->articulat_params.parameter_value [6]
        = (signed short) ((int) AUV_stbd_rpm / 10);
    APNptr->articulat_params.parameter_value [7]
        = (signed short) ((int) fabs (AUV_stbd_rpm) % 10);
}
else cout << "[error attaching articulated parameters node 0: time, "
           << "rudder, planes, rpm]" << endl;

// articulated parameters: Thruster parameters
if (APNptr = attachArticulatParamsNode ((char *) UUV_DIS_pdu,
                                         EntityStatePDU_Type))
{
    // Successful attach, fill in data. See DIS standard paragraph 5.3.3
    APNptr->articulat_params.change = TRUE; // always active
    APNptr->articulat_params.ID = 1; // articulated parameter #
    APNptr->articulat_params.parameter_value [0] = (int) AUV_bow_vertical;
    APNptr->articulat_params.parameter_value [1] = (int) AUV_stern_vertical;
    APNptr->articulat_params.parameter_value [2] = (int) AUV_bow_lateral;
    APNptr->articulat_params.parameter_value [3] = (int) AUV_stern_lateral;
    APNptr->articulat_params.parameter_value [4] = 0;
    APNptr->articulat_params.parameter_value [5] = 0;
    APNptr->articulat_params.parameter_value [6] = 0;
    APNptr->articulat_params.parameter_value [7] = 0;
}
else cout << "[error attaching articulated parameters node 1: thrusters]"
           << endl;

// articulated parameters: Sonar parameters
if (APNptr = attachArticulatParamsNode ((char *) UUV_DIS_pdu,
                                         EntityStatePDU_Type))
{
    // Successful attach, fill in data. See DIS standard paragraph 5.3.3
    APNptr->articulat_params.change = TRUE; // always active
    APNptr->articulat_params.ID = 1; // articulated parameter #
    APNptr->articulat_params.parameter_value [0]
        = (signed short) ((int) AUV_ST1000_bearing) / 10;
    APNptr->articulat_params.parameter_value [1]
        = (signed short) ((int) AUV_ST1000_bearing) % 10;
    APNptr->articulat_params.parameter_value [2]

```

```

        = (signed short)
((int) (AUV_ST1000_range*4.0+0.5));
    APNptr->articulat_params.parameter_value [3]
        = (signed short) ((int) AUV_ST1000_strength);
    APNptr->articulat_params.parameter_value [4]
        = (signed short) ((int) AUV_ST725_bearing) / 10;
    APNptr->articulat_params.parameter_value [5]
        = (signed short) ((int) AUV_ST725_bearing) % 10;
    APNptr->articulat_params.parameter_value [6]
        = (signed short) ((int) (AUV_ST725_range*4.0+0.5));
    APNptr->articulat_params.parameter_value [7]
        = (signed short) ((int) AUV_ST725_strength);
}
else cout << "[error attaching articulated parameters node 2: sonar]"
    << endl;

// Identify dead reckoning algorithm: world coordinates, accelerations zero
// (Algorithm 3)
UUV_DIS_pdu->dead_reckon_params.algorithm = DRAlgo_DRM_RPW;

// send out the multicast PDU
int result = net_write ((char *) UUV_DIS_pdu, EntityStatePDU_Type);

if (result == FALSE)
{
    cout << "DIS_net_write () failed" << endl;
}
else if (TRACE) cout << "DIS_net_write () successful, returning" << endl;

freeEntityStatePDU (UUV_DIS_pdu); // essential to prevent memory leak
// articulated parameters are also freed

return result; // end of DIS_net_write ()

//-----//

void DISNetworkedRigidBody:: DIS_net_close ()
{
    DIS_port_open = FALSE;
    net_close ();
}
//-----//

void DISNetworkedRigidBody:: DISNetworkedRigidBody_initialize ()
{
    RigidBody_initialize (); // inherited method
    time_of_last_PDU = 0.0;
}
//-----//

void DISNetworkedRigidBody:: set_time_of_last_PDU
    (const double new_time_of_last_PDU)
{
    time_of_last_PDU = new_time_of_last_PDU;
}
//-----//

void DISNetworkedRigidBody:: set_ttl (int new_ttl)
{
    cout << "DISNetworkedRigidBody::set_ttl: old ttl = " << (int) ttl;

    if (new_ttl > 16)
    {
        cout << endl;
        cout << "A large ttl value may impact people outside your network "
            << endl;
        cout << "and even around the world!" << endl;
    }
}

```

```

        cout << "Please confirm by entering the new time to live (ttl) "
              << "value (" << new_ttl << ") yourself: ";
        cin >> new_ttl;
        cout << endl;
    }
    if ((new_ttl < 1) || (new_ttl > 255))
    {
        cout << endl;
        cout << "Time to live (ttl) value out of range (1..255), ignored."
              << endl;
        return;
    }

    ttl = (u_char) new_ttl;

    cout << endl;
    cout << "                                new ttl   = "
          << (int) ttl << endl;
}
//-----//

void DISNetworkedRigidBody::set_group (char * new_group)
{
    cout << "DISNetworkedRigidBody::set_group: old group = " << group;

    bzero (group, 20);
    strcpy (group, new_group);

    cout << endl;
    cout << "                                new group = " << group << endl;
}
//-----//

void DISNetworkedRigidBody::set_port (char * new_port)
{
    cout << "DISNetworkedRigidBody::set_port: old port = " << port;

    bzero (port, 6);
    strcpy (port, new_port);

    cout << endl;
    cout << "                                new port  = " << port << endl;
}
//-----//

#endif // DISNETWORKEDRIGIDBODY_C

```

H. *RigidBody.C* Rigid Body

```
/////////////////////////////////////////////////////////////////
/*
Program:      RigidBody.C
Author:       Don Brutzman
Revised:      18 October 94
System:       Irix 5.2
Compiler:     ANSI C++
Compilation:  irix> make dynatest
              irix> CC RigidBody.C -lm -c -g +w

              -c == Produce binaries only, suppressing the link phase.
              +w == Warn about all questionable constructs.

Description:  Rigid body class specification.
              Note: world coordinate system, NOT body coordinate system,
                  thus Euler angles are used.

Advisors:     Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

References:   Fu, K.S., Gonzalez, R.C., and Lee, C.S.G.,
              _Robotics: Control, Sensing, Vision and Intelligence_,
              McGraw-Hill Inc., NY, 1987.

              Cooke, J.C., Zyda, M.J., Pratt, D.R., and McGhee, R.B.,
              "NPSNET: Flight Simulation Dynamic Modeling using
              Quaternions," _PRESENCE_, vol. 1 no. 4, Fall 1992,
              pp. 404-420.

              Cooke, Joseph C., "NPSNET: Flight Simulation Dynamic
              Modeling using Quaternions," masters thesis, Naval
              Postgraduate School, December 1993.

*/
/////////////////////////////////////////////////////////////////

#ifndef RIGIDBODY_C
#define RIGIDBODY_C    // prevent errors if multiple #includes present

#include "Hmatrix.C"

class RigidBody
{
private:
    // member data fields

    double    time_of_posture;

    double     x_dot;        // linear velocity along x axis
    double     y_dot;        // linear velocity along y axis
    double     z_dot;        // linear velocity along z axis
    double     phi_dot;      // angular velocity about x axis
    double     theta_dot;    // angular velocity about y axis
    double     psi_dot;      // angular velocity about z axis

public:
```

```

Hmatrix  hmatrix;          // need to access print & set routines

// constructors and destructor

RigidBody  ()
RigidBody  (const Hmatrix initialhmatrix);

RigidBody  (const Hmatrix initialhmatrix, const double t);

RigidBody  (const double x,
           const double y,
           const double z,
           const double phi,
           const double theta,
           const double psi,
           const double t);

~RigidBody  ()                { /* null body */ }

// operators

RigidBody&  operator =      (const RigidBody &rb_rhs);          // assignment

friend ostream & operator << (ostream& out, RigidBody& rb);

// inspection methods

void        print_rigidbody      () const;

Hmatrix     hmatrix_value        () const;
double      time_of_posture_value () const;

double      x_value              () const;
double      y_value              () const;
double      z_value              () const;
double      phi_value            () const;
double      theta_value          () const;
double      psi_value            () const;

double      x_dot_value          () const;
double      y_dot_value          () const;
double      z_dot_value          () const;
double      phi_dot_value        () const;
double      theta_dot_value      () const;
double      psi_dot_value        () const;

// modifying methods

void        RigidBody_initialize  ();

void        set_velocities        (double new_x_dot,
                                   double new_y_dot,
                                   double new_z_dot,
                                   double new_phi_dot,
                                   double new_theta_dot,
                                   double new_psi_dot);

void        set_linear_velocities (double new_x_dot,
                                   double new_y_dot,
                                   double new_z_dot);

void        set_angular_velocities (double new_phi_dot,
                                    double new_theta_dot,
                                    double new_psi_dot);

void        set_time_of_posture   (double new_time_of_posture);

```

```

        void        update_Hmatrix        (double delta_t);

};

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

//-----//
// constructor methods
//-----//

RigidBody:: RigidBody () // default constructor
{
    Hmatrix.set_identity ();
    time_of_posture = 0.0;
    x_dot          = 0.0;
    y_dot          = 0.0;
    z_dot          = 0.0;
    phi_dot        = 0.0;
    theta_dot      = 0.0;
    psi_dot        = 0.0;
}

//-----//

RigidBody:: RigidBody (const Hmatrix initialhmatrix)
{
    hmatrix = Hmatrix (initialhmatrix);
    time_of_posture = 0.0;
    x_dot      = 0.0;
    y_dot      = 0.0;
    z_dot      = 0.0;
    phi_dot    = 0.0;
    theta_dot  = 0.0;
    psi_dot    = 0.0;
}

//-----//

RigidBody:: RigidBody (const Hmatrix initialhmatrix, const double t)
{
    hmatrix = Hmatrix (initialhmatrix);
    time_of_posture = t;
    x_dot      = 0.0;
    y_dot      = 0.0;
    z_dot      = 0.0;
    phi_dot    = 0.0;
    theta_dot  = 0.0;
    psi_dot    = 0.0;
}

//-----//

RigidBody:: RigidBody (const double x,
                     const double y,
                     const double z,
                     const double phi,
                     const double theta,
                     const double psi,
                     const double t)
{
    hmatrix      = Hmatrix (phi, theta, psi, x, y, z);
    time_of_posture = t;
    x_dot        = 0.0;
    y_dot        = 0.0;
    z_dot        = 0.0;
    phi_dot      = 0.0;
    theta_dot    = 0.0;
    psi_dot      = 0.0;
}

```

```

//-----//
RigidBody& RigidBody:: operator = (const RigidBody &rb_rhs)    // assignment
{
    hmatrix      = rb_rhs.hmatrix;
    time_of_posture = rb_rhs.time_of_posture;
    x_dot        = rb_rhs.x_dot;
    y_dot        = rb_rhs.y_dot;
    z_dot        = rb_rhs.z_dot;
    phi_dot      = rb_rhs.phi_dot;
    theta_dot    = rb_rhs.theta_dot;
    psi_dot      = rb_rhs.psi_dot;
    return *this;
}
//-----//

ostream& operator << (ostream& out, RigidBody& rb)
{
    rb.hmatrix.print_hmatrix ();
    out << "time_of_posture = " << rb.time_of_posture << endl;
    out << "x_dot, y_dot, z_dot, phi_dot, theta_dot, psi_dot> = <"
        << rb.x_dot << ", " << rb.y_dot << ", " << rb.z_dot << ", "
        << rb.phi_dot << ", " << rb.theta_dot << ", " << rb.psi_dot << ">"
        << endl;
    return out;
}
//-----//
// inspection methods
//-----//

void RigidBody:: print_rigidbody ()
const
{
    hmatrix.print_hmatrix ();
    cout << "time_of_posture = " << time_of_posture << endl;
    cout << "< x_dot, y_dot, z_dot, phi_dot, theta_dot, psi_dot> = <"
        << x_dot << ", " << y_dot << ", " << z_dot << ", "
        << phi_dot << ", " << theta_dot << ", " << psi_dot << ">" << endl;
}
//-----//

Hmatrix RigidBody:: hmatrix_value ()    // note this returns an Hmatrix object,
const                                  // not a [4][4] array
{
    return hmatrix;
}
//-----//

double RigidBody:: time_of_posture_value ()
const
{
    return time_of_posture;
}
//-----//

double RigidBody:: x_value ()
const
{
    return hmatrix.x_value ();
}
//-----//

double RigidBody:: y_value ()
const
{
    return hmatrix.y_value ();
}

```

```

}
//-----//

double RigidBody:: z_value ()
const
{
    return hmatrix.z_value ();
}
//-----//

double RigidBody:: phi_value ()
const
{
    return hmatrix.phi_value ();
}
//-----//

double RigidBody:: theta_value ()
const
{
    return hmatrix.theta_value ();
}
//-----//

double RigidBody:: psi_value ()
const
{
    return hmatrix.psi_value ();
}
//-----//

double RigidBody:: x_dot_value ()
const
{
    return x_dot;
}
//-----//

double RigidBody:: y_dot_value ()
const
{
    return y_dot;
}
//-----//

double RigidBody:: z_dot_value ()
const
{
    return z_dot;
}
//-----//

double RigidBody:: phi_dot_value ()
const
{
    return phi_dot;
}
//-----//

double RigidBody:: theta_dot_value ()
const
{
    return theta_dot;
}
//-----//

double RigidBody:: psi_dot_value ()

```

```

const
{
    return psi_dot;
}
//-----//
// modifying methods
//-----//

void RigidBody:: RigidBody_initialize ()
{
    hmatrix.set_identity ();
    time_of_posture = 0.0;
    x_dot          = 0.0;
    y_dot          = 0.0;
    z_dot          = 0.0;
    phi_dot        = 0.0;
    theta_dot      = 0.0;
    psi_dot        = 0.0;
}
//-----//

void RigidBody:: set_velocities (double new_x_dot,
                                double new_y_dot,
                                double new_z_dot,
                                double new_phi_dot,
                                double new_theta_dot,
                                double new_psi_dot)
{
    x_dot = new_x_dot;
    y_dot = new_y_dot;
    z_dot = new_z_dot;
    phi_dot = new_phi_dot;
    theta_dot = new_theta_dot;
    psi_dot = new_psi_dot;
}
//-----//

void RigidBody:: set_linear_velocities
                                (double new_x_dot,
                                double new_y_dot,
                                double new_z_dot)
{
    x_dot = new_x_dot;
    y_dot = new_y_dot;
    z_dot = new_z_dot;
}
//-----//

void RigidBody:: set_angular_velocities
                                (double new_phi_dot,
                                double new_theta_dot,
                                double new_psi_dot)
{
    phi_dot = new_phi_dot;
    theta_dot = new_theta_dot;
    psi_dot = new_psi_dot;
}
//-----//

void RigidBody:: set_time_of_posture (double new_time_of_posture)
{
    time_of_posture = new_time_of_posture;
}
//-----//

void RigidBody:: update_Hmatrix    (double delta_t)
{

```

```

    hmatrix.incremental_rotation    ( phi_dot, theta_dot, psi_dot,  delta_t);
    hmatrix.incremental_translation (Vector3D ( x_dot, y_dot, z_dot), delta_t);
}
//-----//
#endif // RIGIDBODY_C

```

I. *Hmatrix.C* Homogeneous Transform Matrix Mathematics

```

//*****
/*
Program:      Hmatrix.C
Author:       Don Brutzman
Revised:     12 October 94
System:      Iris
Compiler:    ANSI C++
Compilation:  irix> make dynatest
               irix> CC Hmatrix.C -lm -c -g +w

               -c == Produce binaries only, suppressing the link phase.
               +w == Warn about all questionable constructs.

Description:  Homogenous transform matrix class specification
               All angle parameter values are in radians

               rotations are in world coordinate system
               translations are in world coordinate system

Advisors:    Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

References:  Fu, K.S., Gonzalez, R.C., and Lee, C.S.G.,
             _Robotics: Control, Sensing, Vision and Intelligence_,
             McGraw-Hill Inc., NY, 1987.

             Cooke, J.C., Zyda, M.J., Pratt, D.R., and McGhee, R.B.,
             "NPSNET: Flight Simulation Dynamic Modeling using
             Quaternions," _PRESENCE_, vol. 1 no. 4, Fall 1992,
             pp. 404-420.

             Cooke, Joseph C., "NPSNET: Flight Simulation Dynamic
             Modeling using Quaternions," masters thesis, Naval
             Postgraduate School, December 1993.

*/
//*****

#ifndef HMATRIX_C
#define HMATRIX_C // prevent errors if multiple #includes present
#include "Quaternion.C"

class Hmatrix
{
private:
// member data fields
    double  htmatrix [4][4];

public:
// constructors and destructor
    Hmatrix          ();
    Hmatrix          (const double    x,
                     const double    y,
```

```

        const double      z,
        const double      phi,
        const double      theta,
        const double      psi);

Hmatrix      (const Vector3D  position_Vector3D,
              const double    phi,
              const double    theta,
              const double    psi);

Hmatrix      (const Vector3D  position_Vector3D,
              const Vector3D   eulerangles3D);

Hmatrix      (const Vector3D  position_Vector3D,
              const Quaternion posture);

Hmatrix      (const Hmatrix&  input_hmatrix);

~Hmatrix      ()              { /* null body */ }

// operators

Hmatrix&      operator =      (const Hmatrix &h_rhs);          // assignment
Hmatrix&      operator *      (const Hmatrix &h_rhs);          // Hmatrix multiply
Hmatrix&      operator *      (const Vector3D &v_rhs);          // Vector3D multiply

friend ostream& operator << (ostream& os, Hmatrix& h);

// inspection methods

void          print_hmatrix () const;

double        x_value         () const;
double        y_value         () const;
double        z_value         () const;
double        phi_value        () const;
double        theta_value      () const;
double        psi_value        () const;

Quaternion    quaternion_value
              () const;

Vector3D      position         () const;
Vector3D      camera           () const;
double        scale            () const;

double        element          (const int row,                // accessor returns lvalue
                               const int column) const;        // for row/column [1..4]

// modifying methods

void          rotate           (const double    phi,
                               const double    theta,
                               const double    psi);

void          rotate           (const Vector3D rotation3D);

void          rotate_x         (const double    phi);
void          rotate_y         (const double    theta);
void          rotate_z         (const double    psi);

void          incremental_rotation
              (const double    phi_dot,
               const double    theta_dot,
               const double    psi_dot,
               const double    delta_t );

```

```

void      translate      (const double  delta_x,
                          const double  delta_y,
                          const double  delta_z);

void      translate      (const Vector3D translation3D);

void      incremental_translation
                          (const double  x_dot,  const double y_dot,
                          const double  z_dot,  const double delta_t);

void      incremental_translation
                          (const Vector3D velocities3D,
                          const double  delta_t);

void      set_identity   ();

void      set_posture    (const double phi,
                          const double theta,
                          const double psi);

void      set_position   (const Vector3D translation3D);

void      set_camera     (const Vector3D translation3D);
void      move_camera    (const Vector3D translation3D);

void      set_all_scales(const double scale_x,
                          const double scale_y,
                          const double scale_z,
                          const double scale_global);

void      set_scale      (const double scale_global);

};

/////////////////////////////////////////////////////////////////

// rotation matrix conventions:  Cooke et al. Figure 10

// rotation matrix
#define a1      htmatrix[0][0]
#define a2      htmatrix[1][0]
#define a3      htmatrix[2][0]
#define b1      htmatrix[0][1]
#define b2      htmatrix[1][1]
#define b3      htmatrix[2][1]
#define c1      htmatrix[0][2]
#define c2      htmatrix[1][2]
#define c3      htmatrix[2][2]

// position translation vector
#define p_x      htmatrix[0][3]
#define p_y      htmatrix[1][3]
#define p_z      htmatrix[2][3]

// camera perspective transformation
#define c_x      htmatrix[3][0]
#define c_y      htmatrix[3][1]
#define c_z      htmatrix[3][2]

// global scale coefficient
#define hscale   htmatrix[3][3]

//-----//
// constructor methods
//-----//

Hmatrix:: Hmatrix () // default constructor

```

```

{
    set_identity ();
}
//-----//

Hmatrix:: Hmatrix (const double      x,
                   const double      y,
                   const double      z,
                   const double      phi,
                   const double      theta,
                   const double      psi) // constructor
{
    set_identity ();
    rotate      (phi, theta, psi);
    translate    (Vector3D (x, y, z));
}
//-----//

Hmatrix:: Hmatrix (const Vector3D    position_Vector3D,
                   const double      phi,
                   const double      theta,
                   const double      psi)
{
    set_identity ();
    rotate      (phi, theta, psi);
    translate    (position_Vector3D);
}
//-----//

Hmatrix:: Hmatrix (const Vector3D position_Vector3D,
                   const Vector3D eulerangles3D)
{
    set_identity ();
    rotate      (eulerangles3D);
    translate    (position_Vector3D);
}
//-----//

Hmatrix:: Hmatrix (const Vector3D position_Vector3D, const Quaternion posture)
{
    set_identity ();
    rotate      (posture.euler_angles ());
    translate    (position_Vector3D);
}
//-----//

Hmatrix:: Hmatrix (const Hmatrix& input_hmatrix)
{
    for (int row = 0; row <= 3; row++)
    {
        for (int column = 0; column <= 3; column++)
        {
            htmatrix [row][column] = input_hmatrix.element (row+1, column+1);
        }
    }
}
//-----//
// operators
//-----//

Hmatrix& Hmatrix:: operator = (const Hmatrix &h_rhs)        // assignment
{
    for (int row = 0; row <= 3; row++)
    {
        for (int column = 0; column <= 3; column++)
        {
            htmatrix [row][column] = h_rhs.htmatrix [row][column];
        }
    }
}

```

```

    }
    return *this;
}
//-----//

Hmatrix& Hmatrix:: operator * (const Hmatrix &h_rhs)    // Hmatrix multiplication
{
    static Hmatrix hresult = Hmatrix ();

    int row, column, index;

    for (row = 0; row <= 3; row++)
    {
        for (column = 0; column <= 3; column++)
        {
            hresult.htmatrix [row][column] = 0.0;
        }
    }

    for (row = 0; row <= 3; row++)
    {
        for (column = 0; column <= 3; column++)
        {
            for (index = 0; index <= 3; index++)
            {
                hresult.htmatrix [row][column] = hresult.htmatrix [row][column] +
                    htmatrix [row][index] * h_rhs.htmatrix [index][column];
            }
        }
    }

    return hresult;
}
//-----//

Hmatrix& Hmatrix:: operator * (const Vector3D &v_rhs)    // Vector3D multiply
{
    static Hmatrix hresult = Hmatrix ();

    int row, column;
    double position_vector [4];

    position_vector [0] = v_rhs [1];
    position_vector [1] = v_rhs [2];
    position_vector [2] = v_rhs [3];
    position_vector [3] = 1.0;

    for (row = 0; row <= 3; row++)
    {
        for (column = 0; column <= 3; column++)
        {
            hresult.htmatrix [row][column] = 0.0;
        }
    }

    for (row = 0; row <= 3; row++)
    {
        for (column = 0; column <= 3; column++)
        {
            hresult.htmatrix [row][column] =
                htmatrix [row][column] * position_vector [column];
        }
    }

    return hresult;
}
//-----//

```

```

ostream& operator << (ostream& out, Hmatrix& h)
{
    int row;

    for (row = 0; row <= 3; row++)
    {
        out << endl << "["
            << h.htmatrix [row][0] << ", " << h.htmatrix [row][1] << ", "
            << h.htmatrix [row][2] << ", " << h.htmatrix [row][3] << "]"<< endl;
        return (out);
    }
}
//-----//
// inspection methods
//-----//

void Hmatrix:: print_hmatrix ()
const
{
    int row;

    for (row = 0; row <= 3; row++)
    {
        cout << endl << "["
            << htmatrix [row][0] << ", " << htmatrix [row][1] << ", "
            << htmatrix [row][2] << ", " << htmatrix [row][3] << "]"<< endl;
    }
}
//-----//

double Hmatrix:: phi_value ()
const
{
    double theta = theta_value ();
    double result;

    if ((theta == radians ( 90.0)) || (theta == radians (-90.0)))
    {
        cout << "phi_value () warning: theta == " << theta << endl;
    }

    result = acos (arcclamp (c3 / cos (theta))) * sign (b3);
    return result;
}
//-----//

double Hmatrix:: theta_value ()
const
{
    return asin (arcclamp (-a3));
}
//-----//

double Hmatrix:: psi_value ()
const
{
    double theta = theta_value ();
    double result;

    if ((theta == radians ( 90.0)) || (theta == radians (-90.0)))
    {
        cout << "psi_value () warning: theta == " << theta << endl;
    }
}

```

```

        result = acos (arcclamp (a1 / cos (theta_value ()))) * sign (a2);
        return result;
    }

    //-----//

double Hmatrix:: x_value ()
const
{
    return p_x;
}

//-----//

double Hmatrix:: y_value ()
const
{
    return p_y;
}

//-----//

double Hmatrix:: z_value ()
const
{
    return p_z;
}

//-----//

Quaternion Hmatrix:: quaternion_value ()
const
{
    Quaternion qresult = Quaternion ();
    /*
    double    q0, q1, q2, q3;

    q0 = (0.5) * sqrt (a1 + b2 + c3 + 1);
    q1 = 0.0;
    q2 = 0.0;
    q3 = 0.0;

    // ----- Shoemake p. 253, FUNDA or p.41 cooke <<<<<<<<<
    */
    return qresult;
}

//-----//

Vector3D Hmatrix:: position ()
const
{
    return Vector3D (p_x, p_y, p_z);
}

//-----//

Vector3D Hmatrix:: camera ()
const
{
    return Vector3D (c_x, c_y, c_z);
}

//-----//

double Hmatrix:: scale ()
const

```

```

{
    return hscale;
}

//-----//

double Hmatrix::element (const int row,          // accessor returns value
                        const int column)        // with row/column [1..4]
const
{
    if ((row < 1) || (row > 4) || (column < 1) || (column > 4))
    {
        cout << "Warning: Hmatrix.element (" << row << ", " << column <<
            " ) is an invalid accessor (only 1..4 allowed), " <<
            " returning value of 0.0" << endl;

        static double dummy_value = 0.0;
        return dummy_value;
    }

    return htmatrix [row-1][column-1];
}

//-----//
// modifying methods
//-----//

void Hmatrix::rotate (const double phi, const double theta, const double psi)
{
    double hrotation [3][3];
    double hresult [3][3];

    int row, column, index;    // reference: Cooke et al. Figure 10

    double sinphi = sin (phi);
    double cosphi = cos (phi);
    double sintheta = sin (theta);
    double costheta = cos (theta);
    double sinpsi = sin (psi);
    double cospsi = cos (psi);

    hrotation [0][0] = costheta * cospsi;           // a1
    hrotation [1][0] = costheta * sinpsi;           // a2
    hrotation [2][0] = - sintheta;                 // a3
    hrotation [0][1] = sinphi * sintheta * cospsi - cosphi * sinpsi; // b1
    hrotation [1][1] = sinphi * sintheta * sinpsi + cosphi * cospsi; // b2
    hrotation [2][1] = sinphi * costheta;           // b3
    hrotation [0][2] = cosphi * sintheta * cospsi + sinphi * sinpsi; // c1
    hrotation [1][2] = cosphi * sintheta * sinpsi - sinphi * cospsi; // c2
    hrotation [2][2] = cosphi * costheta;           // c3

    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)
        {
            hresult [row][column] = 0.0; // zero accumulators first

            for (index = 0; index <= 2; index++)
            {
                hresult [row][column] = hresult [row][column] +
                    htmatrix [row][index] * hrotation [index][column];
            }
        }
    }
    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)
        {

```

```

        htmatrix [row][column] = hresult [row][column];
    }
}
//-----//

void Hmatrix:: rotate (const Vector3D rotation3D)
{
    rotate (rotation3D [1], rotation3D [2], rotation3D [3]); // note not 0 1 2
}
//-----//

void Hmatrix:: rotate_x (const double phi)
{
    double hrotation [3][3];
    double hresult    [3][3];

    int row, column, index;

    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)
        {
            if (row == column) hrotation [row][column] = 1.0;
            else                hrotation [row][column] = 0.0;
        }

        hrotation [1][1] =  cos (phi);
        hrotation [2][2] =  cos (phi);
        hrotation [2][1] =  sin (phi);
        hrotation [1][2] = - sin (phi);

        for (row = 0; row <= 2; row++)
        {
            for (column = 0; column <= 2; column++)
            {
                hresult [row][column] = 0.0; // zero accumulators first

                for (index = 0; index <= 2; index++)
                {
                    hresult [row][column] = hresult [row][column] +
                        htmatrix [row][index] * hrotation [index][column];
                }
            }
        }

        for (row = 0; row <= 2; row++)
        {
            for (column = 0; column <= 2; column++)
            {
                htmatrix [row][column] = hresult [row][column];
            }
        }
    }
}
//-----//

void Hmatrix:: rotate_y (const double theta)
{
    double hrotation [3][3];
    double hresult    [3][3];

    int row, column, index;

    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)
        {
            if (row == column) hrotation [row][column] = 1.0;

```

```

        else                hrotation [row][column] = 0.0;
    }
}
hrotation [0][0] =  cos (theta);
hrotation [2][2] =  cos (theta);
hrotation [2][0] = - sin (theta);
hrotation [0][2] =  sin (theta);

for (row = 0; row <= 2; row++)
{
    for (column = 0; column <= 2; column++)
    {
        hresult [row][column] = 0.0; // zero accumulators first

        for (index = 0; index <= 2; index++)
        {
            hresult [row][column] = hresult [row][column] +
                htmatrix [row][index] * hrotation [index][column];
        }
    }
}

for (row = 0; row <= 2; row++)
{
    for (column = 0; column <= 2; column++)
    {
        htmatrix [row][column] = hresult [row][column];
    }
}

//-----//

void Hmatrix:: rotate_z (const double psi)
{
    double hrotation [3][3];
    double hresult   [3][3];

    int row, column, index;

    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)
        {
            if (row == column) hrotation [row][column] = 1.0;
            else                hrotation [row][column] = 0.0;
        }
    }
    hrotation [0][0] =  cos (psi);
    hrotation [1][1] =  cos (psi);
    hrotation [1][0] =  sin (psi);
    hrotation [0][1] = - sin (psi);

    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)
        {
            hresult [row][column] = 0.0; // zero accumulators first

            for (index = 0; index <= 2; index++)
            {
                hresult [row][column] = hresult [row][column] +
                    htmatrix [row][index] * hrotation [index][column];
            }
        }
    }
    for (row = 0; row <= 2; row++)
    {
        for (column = 0; column <= 2; column++)

```

```

        {
            htmatrix [row][column] = hresult [row][column];
        }
    }

//-----//

void Hmatrix:: incremental_rotation (const double  phi_dot,
                                    const double theta_dot,
                                    const double  psi_dot,
                                    const double delta_t )
{
    rotate (phi_dot * delta_t, theta_dot * delta_t, psi_dot * delta_t);
}

//-----//

void Hmatrix:: translate (const double delta_x,
                          const double delta_y,
                          const double delta_z)
{
    p_x += delta_x;
    p_y += delta_y;
    p_z += delta_z;
}

//-----//

void Hmatrix:: translate (const Vector3D translation3D)
{
    p_x += translation3D [1];
    p_y += translation3D [2];
    p_z += translation3D [3];
}

//-----//

void Hmatrix:: incremental_translation (const double x_dot,
                                       const double y_dot,
                                       const double z_dot,
                                       const double delta_t)
{
    p_x += x_dot * delta_t;
    p_y += y_dot * delta_t;
    p_z += z_dot * delta_t;
}

//-----//

void Hmatrix:: incremental_translation (const Vector3D velocities3D,
                                       const double delta_t)
{
    p_x += velocities3D [1] * delta_t;
    p_y += velocities3D [2] * delta_t;
    p_z += velocities3D [3] * delta_t;
}

//-----//

void Hmatrix:: set_identity () // default constructor set to identity matrix
{
    for (int row = 0; row <= 3; row++)
    {
        for (int column = 0; column <= 3; column++)
        {
            if (row == column) htmatrix [row][column] = 1.0;
            else               htmatrix [row][column] = 0.0;
        }
    }
}

//-----//

```

```

void Hmatrix:: set_posture (const double phi,
                           const double theta,
                           const double psi)
{
    set_identity ();
    rotate (phi, theta, psi);
}
//-----//

void Hmatrix:: set_position (const Vector3D translation3D)
{
    p_x = translation3D [1];
    p_y = translation3D [2];
    p_z = translation3D [3];
}
//-----//

void Hmatrix:: set_camera (const Vector3D translation3D)
{
    c_x = translation3D [1];
    c_y = translation3D [2];
    c_z = translation3D [3];
}
//-----//

void Hmatrix:: move_camera (const Vector3D translation3D)
{
    c_x += translation3D [1];
    c_y += translation3D [2];
    c_z += translation3D [3];
}
//-----//

void Hmatrix:: set_all_scales (const double scale_x,
                              const double scale_y,
                              const double scale_z,
                              const double scale_global)
{
    a1 *= scale_x;
    b2 *= scale_y;
    c3 *= scale_z;
    hscale *= scale_global;
}
//-----//

void Hmatrix:: set_scale (const double scale_global)
{
    hscale *= scale_global;
}
// restore defines
// restore defines

#undef a1
#undef a2
#undef a3
#undef b1
#undef b2
#undef b3
#undef c1
#undef c2
#undef c3
#undef p_x
#undef p_y
#undef p_z
#undef c_x
#undef c_y
#undef c_z

```

```
#undef hscale
```

```
////////////////////////////////////
```

```
#endif // #ifndef HMATRIX_C
```

J. *Quaternion.C* Quaternion Mathematics

```
/////////////////////////////////////////////////////////////////
/*
Program:      Quaternion.C

Revisions:    Don Brutzman

Revised:      29 SEP 94

System:       Irix

Compiler:      ANSI C++

Compilation:   irix> make dynatest
               irix> CC Quaternion.C -lm -c -g +w

               -c == Produce binaries only, suppressing the link phase.
               +w == Warn about all questionable constructs.

Description:   Quaternion class specifications and implementation
               All angle parameter values are in radians.

Advisors:      Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey

References:    Haynes, Keith, "Computer Graphics Tools for the
               Visualization of Spacecraft Dynamics," masters thesis,
               Naval Postgraduate School, December 1993. Includes
               source code used for initial version of quaternion.c

               Cooke, J.C., Zyda, M.J., Pratt, D.R., and McGhee, R.B.,
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               Quaternions," _PRESENCE_, vol. 1 no. 4, Fall 1992,
               pp. 404-420.

               Cooke, Joseph C., "NPSNET: Flight Simulation Dynamic
               Modeling using Quaternions," masters thesis, Naval
               Postgraduate School, December 1993.

               Chou, Jack C.K., "Quaternion Kinematic and Dynamic
               Differential Equations," IEEE Transactions on Robotics
               and Automation, vol. 8 no. 1, February 1992, pp.53-64.

               Funda, Janez, Taylor, Russell, and Paul, Richard P.,
               "On Homogenous Transforms, Quaternions, and Computational
               Efficiency," IEEE Transactions on Robotics and Automation,
               vol. 6 no. 3, June 1990, pp. 382-388.

               Shoemake, Ken, "Animating Rotation with Quaternion Curves,"
               Association for Computing Machinery _SIGGRAPH_ Proceedings,
               vol. 19 no. 3, July 22-26 1985, pp. 245-254.

*/
/////////////////////////////////////////////////////////////////

#ifndef QUATERNION_C
#define QUATERNION_C    // prevent errors if multiple #includes present

#include "Vector3D.C"

#define PI      3.1415926535897932

#ifdef TRUE
#undef TRUE
#endif
#endif
```

```

#ifdef FALSE
#undef FALSE
#endif

#define TRUE 1
#define FALSE 0

////////////////////////////////////////////////////////////////

// utility function prototypes

double    sign      (double x);

double    degrees   (double x); // radians input

double    radians   (double x); // degrees input

double    arclamp   (double x);

double    dnormalize (double angle_radians); // returns 0..2PI

int       inormalize (double angle_radians) // returns 0..359
        {return (int) (degrees (angle_radians) + 0.5) % 360;}

////////////////////////////////////////////////////////////////

class Quaternion
{
private:

// member data fields

    double    q0;
    double    q1;
    double    q2;
    double    q3;

public:

// constructors and destructor

    Quaternion      ();

    Quaternion      (const double phi,
                    const double theta,
                    const double psi);

    Quaternion      (const double new_q0,
                    const double new_q1,
                    const double new_q2,
                    const double new_q3);

    Quaternion      (const Quaternion& q);

    ~Quaternion()    { /* null body */ }

// operators

    Quaternion& operator =      (const Quaternion& q_rhs);
    Quaternion operator +      (const Quaternion& q_rhs);
    Quaternion operator -      (const Quaternion& q_rhs);
    Quaternion operator *      (const Quaternion& q_rhs);
    Quaternion operator *      (double scalar);
    double& operator []      (int);

    friend ostream& operator << (ostream& out, Quaternion& q);

```

```

// inspection methods

void      print      ();

double    phi_value   () const; // Euler angle roll
double    theta_value () const; // Euler angle pitch
double    psi_value   () const; // Euler angle yaw

double    magnitude   () const; // Normally 1.0, unit quaternions
Vector3D  euler_angles () const; // Euler angle phi, theta, psi
                                   // (roll, pitch, yaw)
                                   // more efficient than individual calls

Quaternion conjugate   () const; // negates vector part
Quaternion inverse     () const; // negates vector part & normalizes

// modifying methods

void      rotate      (const double delta_phi,
                       const double delta_theta,
                       const double delta_psi );

void      incremental_rotate (const double P, const double Q,
                              const double R, const double delta_t);

void      update       (double P, double Q, double R,
                       double seconds);

void      set          (double phi, double theta, double psi,
                       double rotation);

void      normalize     ();

};

/////////////////////////////////////////////////////////////////

double sign (double x)
{
    if (x > 0.0) return 1.0;
    else if (x < 0.0) return -1.0;
    else return 1.0;
}

//-----//

double degrees (double x) // radians input
{
    return x * 180.0 / PI;
}

//-----//

double radians (double x) // degrees input
{
    return x * PI / 180.0;
}

//-----//

double arcclamp (double x)
{
    if (x > 1.0)
    {
        x = 1.0;
        // cout << " arcclamp reduced " << x << " to 1.0" << endl;
    }
    else if (x < -1.0)
    {

```

```

        x = -1.0;
        cout << " arclamp raised " << x << " to -1.0" << endl;
    }
    return x;
}
//-----//

double dnormalize (double angle_radians)
{
    double new_angle = angle_radians;

    while (new_angle > 2*PI) new_angle -= 2*PI;
    while (new_angle < 0.0 ) new_angle += 2*PI;
    return new_angle;
}
//-----//
// constructor methods
//-----//

Quaternion::Quaternion ()
{
    q0 = 1.0;
    q1 = 0.0;
    q2 = 0.0;
    q3 = 0.0;
}
//-----//

Quaternion::Quaternion (const double phi,
                        const double theta,
                        const double psi)
{
    // reference: Cooke thesis p. 41

    double r, p, y, cosr, cosp, cosy, sinr, sinp, siny;

    r = (phi / 2.0);    p = (theta / 2.0);    y = (psi / 2.0);
    cosr = cos (r);     cosp = cos (p);       cosy = cos (y);
    sinr = sin (r);     sinp = sin (p);       siny = sin (y);
    q0 = (cosr * cosp * cosy) + (sinr * sinp * siny);
    q1 = (sinr * cosp * cosy) - (cosr * sinp * siny);
    q2 = (cosr * sinp * cosy) + (sinr * cosp * siny);
    q3 = - (sinr * sinp * cosy) + (cosr * cosp * siny);
}
//-----//

Quaternion::Quaternion (const double new_q0,
                        const double new_q1,
                        const double new_q2,
                        const double new_q3)
{
    q0 = new_q0;
    q1 = new_q1;
    q2 = new_q2;
    q3 = new_q3;
}
//-----//

Quaternion::Quaternion (const Quaternion& q)
{
    q0 = q.q0;
    q1 = q.q1;
    q2 = q.q2;
    q3 = q.q3;
}
//-----//
// operators

```

```

//-----//
Quaternion& Quaternion:: operator = (const Quaternion& q_rhs)
{
    q0 = q_rhs.q0;
    q1 = q_rhs.q1;
    q2 = q_rhs.q2;
    q3 = q_rhs.q3;
    return *this;
}
//-----//

Quaternion Quaternion:: operator + (const Quaternion& q_rhs)
{
    static Quaternion sum;

    sum.q0 = q0 + q_rhs.q0;
    sum.q1 = q1 + q_rhs.q1;
    sum.q2 = q2 + q_rhs.q2;
    sum.q3 = q3 + q_rhs.q3;
    return sum;
}
//-----//

Quaternion Quaternion:: operator - (const Quaternion& q_rhs)
{
    static Quaternion difference;

    difference.q0 = q0 - q_rhs.q0;
    difference.q1 = q1 - q_rhs.q1;
    difference.q2 = q2 - q_rhs.q2;
    difference.q3 = q3 - q_rhs.q3;
    return difference;
}
//-----//

Quaternion Quaternion:: operator * (const Quaternion& q_rhs)
{
    static Quaternion prod;
    prod.q0 = (q0 * q_rhs.q0) - (q1 * q_rhs.q1) -
              (q2 * q_rhs.q2) - (q3 * q_rhs.q3);
    prod.q1 = (q1 * q_rhs.q0) + (q0 * q_rhs.q1) -
              (q3 * q_rhs.q2) + (q2 * q_rhs.q3);
    prod.q2 = (q2 * q_rhs.q0) + (q3 * q_rhs.q1) -
              (q0 * q_rhs.q2) + (q1 * q_rhs.q3);
    prod.q3 = (q3 * q_rhs.q0) + (q2 * q_rhs.q1) -
              (q1 * q_rhs.q2) + (q0 * q_rhs.q3);
    return prod;
}
//-----//

Quaternion Quaternion:: operator * (double scalar)
{
    static Quaternion product;

    product.q0 = q0 * scalar;
    product.q1 = q1 * scalar;
    product.q2 = q2 * scalar;
    product.q3 = q3 * scalar;
    return product;
}
//-----//

double& Quaternion:: operator [] (int n)
{
    if (n == 0)
    {

```

```

        return q0;
    }
    if (n == 1)
    {
        return q1;
    }
    if (n == 2)
    {
        return q2;
    }
    if (n == 3)
    {
        return q3;
    }
    cout << "Warning: quaternion[" << n << "] is an invalid accessor"
        << " (only 0..3 allowed), returning value of 0.0" << endl;
    static double dummy_value = 0.0;
    return dummy_value;
}
//-----//

ostream& operator << (ostream& out, Quaternion& q)
{
    out << "[" << q.q0 << ", " << q.q1 << ", "
        << q.q2 << ", " << q.q3 << "]" ;
    return (out);
}
//-----//
// inspection methods
//-----//

void Quaternion:: print ()
{
    cout << "[" << q0 << ", " << q1 << ", "
        << q2 << ", " << q3 << "]" ;
}
//-----//

double Quaternion:: phi_value ()    // Euler angle roll
const
{
    return  acos (arcclamp ((q0*q0 - q1*q1 - q2*q2 + q3*q3)
        / cos (theta_value ())))
        * sign (q2*q3 + q0*q1);
}
//-----//

double Quaternion:: theta_value () // Euler angle pitch
const
{
    return asin (arcclamp (-2.0 * (q1*q3 - q0*q2)));
}
//-----//

double Quaternion:: psi_value ()    // Euler angle yaw
const
{
    return  acos (arcclamp ((q0*q0 + q1*q1 - q2*q2 - q3*q3)
        / cos (theta_value ())))
        * sign (q1*q2 + q0*q3);
}
//-----//

```

```

double Quaternion:: magnitude ()
{
    return sqrt((q0 * q0) + (q1 * q1) + (q2 * q2) + (q3 * q3));
}
//-----//

Vector3D Quaternion:: euler_angles ()    // Euler angle  phi,  theta, psi
                                         //              (roll, pitch, yaw)
                                         // more efficient than individual calls

const
{
    double qq0, qq1, qq2, qq3, phi, theta, psi, costheta; // locals hide methods

    qq0    = q0 * q0; // force optimization of squaring computations
    qq1    = q1 * q1;
    qq2    = q2 * q2;
    qq3    = q3 * q3;

    theta  = asin (arcclamp (-2.0 * (q1*q3 - q0*q2)));
    costheta = cos (theta);

    phi    =   acos (arcclamp ((qq0 - qq1 - qq2 + qq3) / costheta))
              * sign (q2*q3 + q0*q1);

    psi    =   acos (arcclamp ((qq0 + qq1 - qq2 - qq3) / costheta))
              * sign (q1*q2 + q0*q3);

    return Vector3D (phi, theta, psi);
}
//-----//

Quaternion Quaternion:: conjugate ()    // negates vector part

const
{
    return Quaternion (q0, - q1, - q2, - q3);
}
//-----//

Quaternion Quaternion:: inverse ()    // negates vector part

const
{
    static Quaternion qresult;

    qresult = conjugate ();
    qresult.normalize ();
    return qresult;
}
//-----//
// modifying methods
//-----//

void Quaternion:: rotate (const double delta_phi,
                        const double delta_theta,
                        const double delta_psi )
{
    Quaternion rotation;

    rotation.q0= -0.5*((q1 * delta_phi)  +(q2 * delta_theta)+(q3 * delta_psi));
    rotation.q1=  0.5*((q0 * delta_phi)  +(q2 * delta_psi)  -(q3 * delta_theta));
    rotation.q2=  0.5*((q0 * delta_theta)+(q3 * delta_phi)  -(q1 * delta_psi));

```

```

rotation.q3= 0.5*((q0 * delta_psi) +(q1 * delta_theta)-(q2 * delta_phi));

q0 += rotation.q0;
q1 += rotation.q1;
q2 += rotation.q2;
q3 += rotation.q3;
normalize ();
return;
}
//-----//

void Quaternion:: incremental_rotate (const double P, const double Q,
                                     const double R, const double delta_t)
{
    Quaternion rotation;

    rotation.q0 = -0.5 * delta_t * ((q1 * P) + (q2 * Q) + (q3 * R));
    rotation.q1 = 0.5 * delta_t * ((q0 * P) + (q2 * R) - (q3 * Q));
    rotation.q2 = 0.5 * delta_t * ((q0 * Q) + (q3 * P) - (q1 * R));
    rotation.q3 = 0.5 * delta_t * ((q0 * R) + (q1 * Q) - (q2 * P));

    q0 += rotation.q0;
    q1 += rotation.q1;
    q2 += rotation.q2;
    q3 += rotation.q3;
    normalize ();
    return;
}
//-----//

void Quaternion:: update (double P, double Q, double R, double seconds)
{
    double hh = seconds * 0.5;
    double h6 = seconds / 6.0;
    Quaternion y = *this, dym, dyt, yt, dydx;

    dydx.q0 = -0.5 * ((q1 * P) + (q2 * Q) + (q3 * R));
    dydx.q1 = 0.5 * ((q0 * P) + (q2 * R) - (q3 * Q));
    dydx.q2 = 0.5 * ((q0 * Q) + (q3 * P) - (q1 * R));
    dydx.q3 = 0.5 * ((q0 * R) + (q1 * Q) - (q2 * P));

    yt.q0 = y.q0 + hh * dydx.q0;
    yt.q1 = y.q1 + hh * dydx.q1;
    yt.q2 = y.q2 + hh * dydx.q2;
    yt.q3 = y.q3 + hh * dydx.q3;

    dyt.q0 = -0.5 * ((yt.q1 * P) + (yt.q2 * Q) + (yt.q3 * R));
    dyt.q1 = 0.5 * ((yt.q0 * P) + (yt.q2 * R) - (yt.q3 * Q));
    dyt.q2 = 0.5 * ((yt.q0 * Q) + (yt.q3 * P) - (yt.q1 * R));
    dyt.q3 = 0.5 * ((yt.q0 * R) + (yt.q1 * Q) - (yt.q2 * P));

    yt.q0 = y.q0 + hh * dyt.q0;
    yt.q1 = y.q1 + hh * dyt.q1;
    yt.q2 = y.q2 + hh * dyt.q2;
    yt.q3 = y.q3 + hh * dyt.q3;

    dym.q0 = -0.5 * ((yt.q1 * P) + (yt.q2 * Q) + (yt.q3 * R));
    dym.q1 = 0.5 * ((yt.q0 * P) + (yt.q2 * R) - (yt.q3 * Q));
    dym.q2 = 0.5 * ((yt.q0 * Q) + (yt.q3 * P) - (yt.q1 * R));
    dym.q3 = 0.5 * ((yt.q0 * R) + (yt.q1 * Q) - (yt.q2 * P));

    yt.q0 = y.q0 + seconds * dym.q0;
    yt.q1 = y.q1 + seconds * dym.q1;
    yt.q2 = y.q2 + seconds * dym.q2;
    yt.q3 = y.q3 + seconds * dym.q3;

    dym.q0 = dym.q0 + dyt.q0;

```

```

dym.q1 = dym.q1 + dyt.q1;
dym.q2 = dym.q2 + dyt.q2;
dym.q3 = dym.q3 + dyt.q3;

dyt.q0 = -0.5 * ((yt.q1 * P) + (yt.q2 * Q) + (yt.q3 * R));
dyt.q1 = 0.5 * ((yt.q0 * P) + (yt.q2 * R) - (yt.q3 * Q));
dyt.q2 = 0.5 * ((yt.q0 * Q) + (yt.q3 * P) - (yt.q1 * R));
dyt.q3 = 0.5 * ((yt.q0 * R) + (yt.q1 * Q) - (yt.q2 * P));

q0 = y.q0 + h6 * (dydx.q0 + dyt.q0 + 2.0 * dym.q0);
q1 = y.q1 + h6 * (dydx.q1 + dyt.q1 + 2.0 * dym.q1);
q2 = y.q2 + h6 * (dydx.q2 + dyt.q2 + 2.0 * dym.q2);
q3 = y.q3 + h6 * (dydx.q3 + dyt.q3 + 2.0 * dym.q3);

normalize ();
}
//-----//

void Quaternion:: set (double phi, double theta, double psi, double twist)
{
    q0 = cos (0.5 * twist);
    q1 = cos (phi) * sin (0.5 * twist);
    q2 = cos (theta) * sin (0.5 * twist);
    q3 = cos (psi) * sin (0.5 * twist);
}
//-----//

void Quaternion:: normalize()
{
    double m = magnitude ();
    if (m > 0.0)
    {
        q0 /= m;
        q1 /= m;
        q2 /= m;
        q3 /= m;
    }
}
//-----//

////////////////////////////////////

#endif // #ifndef QUATERNION_C

```

K. *Vector3D.C* 3D Vector Mathematics

```
/////////////////////////////////////////////////////////////////
/*
Program:          Vector3D.C

Original Author:  Keith Haynes

Revisions:        Don Brutzman

Revised:          12 FEB 94

System:           Iris/PC

Compiler:         ANSI C++

Compilation:      irix> CC Vector3D.C -lm -c -g +w

                  -c == Produce binaries only, suppressing the link phase.
                  +w == Warn about all questionable constructs.

Description:      Vector3D class specifications and implementation

Advisors:         Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey
*/
/////////////////////////////////////////////////////////////////

#ifndef VECTOR3D_C
#define VECTOR3D_C      // prevent errors in multiple #includes present

#include <iostream.h>
#include <iomanip.h>
#include <math.h>

class Vector3D
{
// member data fields

    double x;
    double y;
    double z;

public:

// member constructor and destructor functions

    Vector3D          ();
    Vector3D          (double a, double b, double c);
    Vector3D          (const Vector3D&);
    ~Vector3D ()      { /* null body */ }

// operators

    Vector3D & operator = (const Vector3D&);
    Vector3D operator + (const Vector3D&);
    Vector3D operator - (const Vector3D&);
    double operator * (const Vector3D&); // dot product
    Vector3D operator * (double);         // scalar multiplication
    Vector3D operator / (double);         // scalar division
    Vector3D operator ^ (const Vector3D&); // cross product
    double & operator [] (int) const;

// inspection methods

```

```

        double    magnitude    ();
        friend    ostream & operator << (ostream& os, Vector3D& v);
        void      print ();

// modifying methods

        void      normalize    ();
        void      normalize    (double);
};

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

//default constructor
Vector3D::Vector3D()
{
    x = 0.0;
    y = 0.0;
    z = 0.0;
}

//constructor using three doubles
Vector3D::Vector3D(double a, double b, double c)
{
    x = a;
    y = b;
    z = c;
}

//constructor using another Vector3D
Vector3D::Vector3D(const Vector3D& v)
{
    x = v.x;
    y = v.y;
    z = v.z;
}

//Assignment operator - the function must return a reference to a Vector
//instead of a Vector for assignment to work properly
Vector3D& Vector3D::operator=(const Vector3D& v)
{
    x = v.x;
    y = v.y;
    z = v.z;
    return *this;
}

//Vector addition operator
Vector3D Vector3D::operator+(const Vector3D& v)
{
    Vector3D sum;
    sum.x = v.x + x;
    sum.y = v.y + y;
    sum.z = v.z + z;
    return sum;
}

//Vector subtraction
Vector3D Vector3D::operator-(const Vector3D& v)
{
    Vector3D diff;
    diff.x = x - v.x;
    diff.y = y - v.y;
    diff.z = z - v.z;
    return diff;
}

//Vector dot product

```

```

double Vector3D::operator*(const Vector3D& v)
{
    double dot;
    dot = (v.x * x) + (v.y * y) + (v.z * z);
    return dot;
}

//scalar multiplication
Vector3D Vector3D::operator*(double n)
{
    Vector3D mult;
    mult.x = x * n;
    mult.y = y * n;
    mult.z = z * n;
    return mult;
}

//scalar division - it is the user responsibility to make sure that n is not
zero
Vector3D Vector3D::operator/(double n)
{
    Vector3D result;
    result.x = x / n;
    result.y = y / n;
    result.z = z / n;
    return result;
}

//Vector cross product
Vector3D Vector3D::operator^(const Vector3D& v)
{
    Vector3D cross;
    cross.x = (y * v.z) - (v.y * z);
    cross.y = -((x * v.z) - (v.x * z));
    cross.z = (x * v.y) - (v.x * y);
    return cross;
}

//the << operator is to be used with output stream out
ostream& operator << (ostream& out, Vector3D& v)
{
    out << "[" << v.x << ", " << v.y << ", " << v.z << "]\n";
    return (out);
}

void Vector3D:: print ()
{
    cout << "[" << x << ", " << y << ", " << z << "]\n";
}

//allows access to the components of the Vector3D. it must return a reference
//in order for assignment to work
double& Vector3D::operator[](int n)
const
{
    static double result;
    if (n == 1)
    {
        result = x;
        return result;
    }
    if (n == 2)
    {
        result = y;
        return result;
    }
}

```

```

        if (n == 3)
        {
            result = z;
            return result;
        }
        cout << "Warning: Vector3D[" << n << "] is an invalid accessor"
              << " (only 1..3 allowed), returning value of 0.0" << endl;

        static double dummy_value = 0.0;
        return dummy_value;
    }

//returns the magnitude of the Vector
double Vector3D::magnitude()
{
    return sqrt((x * x) + (y * y) + (z * z));
}

//normalizes the Vector to one
void Vector3D::normalize()
{
    double m = sqrt((x * x) + (y * y) + (z * z));
    if (m)
    {
        x = x / m;
        y = y / m;
        z = z / m;
    }
}

//normalize the Vector to d
void Vector3D::normalize(double d)
{
    double m = sqrt((x * x) + (y * y) + (z * z));
    if (m)
    {
        x = d * x / m;
        y = d * y / m;
        z = d * z / m;
    }
}

////////////////////////////////////

#endif // #ifndef VECTOR3D_C

```

L. *Makefile for Hydrodynamics Classes*

```
# Makefile dynamics model for underwater virtual world
# 14 October 94   Don Brutzman

SGIIRIX4FLAGS    = -O2

#####
# DIS includes

INCS              = -I/n/dude/work/brutzman/DIS.mcast/h
LIB_DIR           = -L/n/dude/work/brutzman/DIS.mcast/src
LIB               = /n/dude/work/brutzman/DIS.mcast/src/libdis_client.a
LIB_ARG           = -ldis_client -lmpc -lm
HDR_PATH          = /n/dude/work/brutzman/DIS.mcast/h/
HDRS              = $(HDR_PATH)pdu.h $(HDR_PATH)disdefs.h

#####

CCFLAGS          = +w $(SGIIRIX4FLAGS)

#INCS             = -I/n/elsie/work3/macedoni/net/mcast/network/h
#LIB_DIR          = -L/n/elsie/work3/macedoni/net/mcast/network/bin
#LIB              = /n/elsie/work3/macedoni/net/mcast/network/bin/libdis_client.a
#LIB_ARG          = -ldis_client -lmpc -lm

#HDR_PATH         = /n/elsie/work3/macedoni/net/mcast/network/h/
#HDRS             = $(HDR_PATH)pdu.h $(HDR_PATH)disdefs.h

#NET_DIR          = /n/elsie/work3/macedoni/net/mcast/network/src/
#NET_DIR          = /n/dude/work/brutzman/DIS.mcast/src
#NETOBS           = $(NET_DIR)attach.o $(NET_DIR)client_lib.o \
#                  $(NET_DIR)free.o $(NET_DIR)mallocs.o $(NET_DIR)sends.o \
#                  $(NET_DIR)recvs.o $(NET_DIR)protocol.o

OBS = dynamics.o      AUVsocket.o      Vector3D.o      Quaternion.o \
      Hmatrix.o       RigidBody.o       DISNetworkedRigidBody.oUUVBody.o \
      SonarModel.o    math_utilities.o

#####

dynamics: $(LIB) $(HDRS) $(OBS)
    @echo "Linking..."
    CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(OBS) $(NETOBS) $(INCS) $(LIB_ARG) \
    -o dynamics

# Makefile requirement is that no libraries are linked to the objects

Vector3D.o: Vector3D.C
    CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG) \
    -c Vector3D.C -o Vector3D.o

Quaternion.o: Quaternion.C Vector3D.C
    CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG) \
    -c Quaternion.C -o Quaternion.o

Hmatrix.o: Hmatrix.C Vector3D.C Quaternion.C
    CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG) \
    -c Hmatrix.C -o Hmatrix.o
```

```

RigidBody.o: RigidBody.C Hmatrix.C
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c RigidBody.C -o RigidBody.o

AUVsocket.o: AUVsocket.C AUVglobals.H UUVmodel.H Quaternion.C $(HDRS)
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c AUVsocket.C -o AUVsocket.o

DISNetworkedRigidBody.o: DISNetworkedRigidBody.C AUVglobals.H UUVmodel.H\
RigidBody.C $(HDRS)
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c DISNetworkedRigidBody.C -o DISNetworkedRigidBody.o

SonarModel.o: SonarModel.C
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c SonarModel.C -o SonarModel.o

UUVBody.o: UUVBody.C AUVglobals.H UUVmodel.H SonarModel.C AUVsocket.C\
DISNetworkedRigidBody.C
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c UUVBody.C -o UUVBody.o

dynamics.o: dynamics.C AUVglobals.H UUVmodel.H UUVBody.C $(HDRS)
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c dynamics.C -o dynamics.o

math_utilities.o: math_utilities.C
CC $(SGIIRIX4FLAGS) $(LIB_DIR) $(NETOBS) $(INCS) $(LIB_ARG)\
-c math_utilities.C -o math_utilities.o

# $(OBS): AUVglobals.H UUVmodel.H $(HDRS)
# CC -c $(CCFLAGS) $(INCS) $*.C

# utilities:

delete:
rm -f core *.o *.a a.out dynamics

clean:
rm -f core *.o *.a a.out

all: delete dynamics

```

VI. SONAR MODEL

A. *SonarModel.C* Geometric Sonar Model

```
////////////////////////////////////
/*
Program:          SonarModel.C
Description:      Underwater vehicle geometric sonar model
Revised:         21 October 94
System:          Irix
Compiler:        ANSI C++
Compilation:      irix> make dynamics
                  irix> CC SonarModel.C -lm -c -g +w

                  -c == Produce binaries only, suppressing the link phase.
                  +w == Warn about all questionable constructs.

Advisors:        Dr. Mike Zyda, Dr. Bob McGhee and Dr. Tony Healey
Author:          Don Brutzman                      brutzman@cs.nps.navy.mil
                  Code OR/Br
                  Naval Postgraduate School        (408) 656-2149 work
                  Monterey CA 93943-5000           (408) 656-2595 fax

References:

Status:          Only pool geometric model included

Future work:     Comments and suggestions are welcome!

*/
////////////////////////////////////
#ifndef SONARMODEL_C
#define SONARMODEL_C    // prevent errors if multiple #includes present
#include "AUVsocket.C"

int    precede      (double angle1, double angle2);
int    precede_radians (double angle1, double angle2);
void    test_tank_sonar_model (); // parallelize & generalize this sonar model
                                     // for all objects in vw, using Ziomek's RRA
double radian_normalize (double rads);
double radian_normalize2 (double rads);

////////////////////////////////////
/*-----*/
/* excerpt from geometric reasoning circle world circle.c */
*/
```

```

/* Boolean function for angle precedence */
int precede (double angle1, double angle2)
{
    /* angles are any real angles in degrees */
    /* return TRUE if angle1 precedes angle2, */
    /* return FALSE otherwise */
    /* note that the input angles are individually normalized to ensure validity */
    if (normalize2 (normalize2 (angle2) - normalize2 (angle1)) > 0.0)
        return TRUE;
    else
        return FALSE;
}
/*-----*/

double radian_normalize (double rads) /* radians input*/
{
    double result = rads;

    while (result < 0.0) result += 2.0 * PI;
    while (result >= 2.0 * PI) result -= 2.0 * PI;

    return result;
}
/*-----*/

double radian_normalize2 (double rads) /* radians input*/
{
    double result = rads;

    while (result <= - PI) result += 2.0 * PI;
    while (result > PI) result -= 2.0 * PI;

    return result;
}
/*-----*/
/* excerpt from geometric reasoning circle world circle.c */
/* Boolean function for angle precedence */
int precede_radians (double angle1, double angle2)
{
    /* angles are any real angles in degrees */
    /* return TRUE if angle1 precedes angle2, */
    /* return FALSE otherwise */
    /* note that the input angles are individually normalized to ensure validity */
    if (radian_normalize2 (radian_normalize2 (angle2) -
        radian_normalize2 (angle1)) > 0.0)
        return TRUE;
    else
        return FALSE;
}
/*-----*/

```

```

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
void test_tank_sonar_model () // parallelize & generalize this sonar model
{
    double SA, SB, SC, SD; // angles from sonar to corners

    // Test tank coordinates:      A (-10, 10)  +--+ (10, 10) B      X-axis
    //                               |      |      ^
    //                               |      |      |
    //                               D (-10, -10) +--+ (10, -10) C    +-->Y-axis

    double return_x, return_y, distance; // intersect coordinates & distance

    // AUV_ST1000_bearing and AUV_ST725_bearing determined by vehicle control

    AUV_ST1000_range = 0.0; // ST_1000 conical pencil beam bearing
    AUV_ST1000_strength = 0.0; // ST_1000 conical pencil beam range
                                // ST_1000 conical pencil beam strength

    AUV_ST725_range = 0.0; // ST_725 1 x 24 sector beam bearing
    AUV_ST725_strength = 0.0; // ST_725 1 x 24 sector beam range
                                // ST_725 1 x 24 sector beam strength

    double sonar_x = AUV_x + cos (AUV_psi) * AUV_ST1000_x_offset;
    double sonar_y = AUV_y + sin (AUV_psi) * AUV_ST1000_x_offset;

    // remove these lines when auv vw viewer includes sonar offset
    sonar_x = AUV_x;
    sonar_y = AUV_y;

    double sonar_psi = AUV_psi + radians (AUV_ST1000_bearing);

    if ((AUV_x <= 10.0) && (AUV_x >= -10.0) &&
        (AUV_y <= 10.0) && (AUV_y >= -10.0) &&
        (AUV_z <= 50.0) && (AUV_z >= 41.0))
    {
        AUV_ST1000_strength = 10.0; // return expected
        AUV_ST725_strength = 10.0; // return expected

        // note that a reversed x,y calling sequence is necessary
        // in order to get correct quadrant alignment
        SA = atan2 ((-10.0) - sonar_y, (10.0) - sonar_x);
        SB = atan2 ((10.0) - sonar_y, (10.0) - sonar_x);
        SC = atan2 ((10.0) - sonar_y, (-10.0) - sonar_x);
        SD = atan2 ((-10.0) - sonar_y, (-10.0) - sonar_x);

        if (TRACE)
        {
            cout << "AUV_x = " << AUV_x
                  << ", AUV_y = " << AUV_y
                  << ", AUV_psi = " << degrees (AUV_psi) << endl;
            cout << "sonar_x = " << sonar_x
                  << ", sonar_y = " << sonar_y
                  << ", sonar_psi = " << degrees (sonar_psi) << endl;
            cout << "SA = " << degrees (SA)
                  << ", SB = " << degrees (SB)
                  << ", SC = " << degrees (SC)
                  << ", SD = " << degrees (SD)
                  << endl;
            cout << "precede_radians (SA, AUV_psi) = "
                  << precede_radians (SA, AUV_psi) << endl;
        }

        if (precede_radians (SA, AUV_psi)
            && precede_radians (AUV_psi, SB))
    }
}

```

```

    if (TRACE) cout << "SECTOR I" << endl;
    return_x = 10.0;
    return_y = sonar_y + sin (sonar_psi) * (10.0 - sonar_x);
}
else if ( precede_radians (SB, sonar_psi)
    && precede_radians (sonar_psi, SC))
{
    if (TRACE) cout << "SECTOR II" << endl;
    return_x = sonar_x - sin (sonar_psi - PI/2.0) * (10.0 - sonar_y);
    return_y = 10.0;
}
else if ( precede_radians (SC, sonar_psi)
    && precede_radians (sonar_psi, SD))
{
    if (TRACE) cout << "SECTOR III" << endl;
    return_x = - 10.0;
    return_y = sonar_y - sin (sonar_psi - PI) * (sonar_x + 10.0);
}
else if ( precede_radians (SD, sonar_psi)
    && precede_radians (sonar_psi, SA))
{
    if (TRACE) cout << "SECTOR IV" << endl;
    return_x = sonar_x + sin (sonar_psi + PI/2.0) * (sonar_y + 10.0);
    return_y = - 10.0;
}
else cout << "Computational sonar error, no sector was determined."
    << endl;

distance = sqrt ( (return_x - sonar_x) * (return_x - sonar_x)
    + (return_y - sonar_y) * (return_y - sonar_y));

AUV_ST1000_range = distance;
AUV_ST725_range = distance;

if (TRACE)
{
    cout << "return_x = " << return_x
        << ", return_y = " << return_y << endl;

    cout << "AUV_ST1000_range = " << AUV_ST1000_range
        << ", AUV_ST725_range = " << AUV_ST725_range << endl;
}
}
else return; // outside of test tank, default return is 0
} // end test_tank_sonar_model

////////////////////////////////////
#endif // SONARMODEL_C

```

VII. NETWORKING

A. Introduction

The principal networking code used in the underwater virtual world has already been presented in previous listings. Source programs *execution.c* and *AUVsocket.c* implement socket communications between robot and virtual world, while *DISNetworkedRigidBody.C* and *viewer.C* communicate via DIS PDUs over the MBone. These communications links were not created from scratch. The following test programs were used in program development and are included as valid standalone applications that can be used to test network software, independently of the robot or computer graphics applications.

os9sender.c and *os9server.c* are a client/server pair used to open test and close a point-to-point socket. What is unusual about these programs is that they were developed to operate interchangeably on either Unix systems using Berkeley Software Distribution (BSD) 4.3 network routines, or on OS-9 processors using Microware-provided network routines (Microware 91a, 91b). Network code is difficult to debug so extensive trace options are provided to assist in diagnosing difficulties.

Prior to the current multicast version (2.0.3) of the DIS library distribution, all DIS interfaces used broadcast or unicast transport protocols. This meant that all network interactions between DIS applications were restricted to a single local area network (LAN). Such a limitation is unacceptable if an underwater virtual world is to be capable of communicating globally across the Internet. *disbridge.c* was written to create a socket bridge between LANs which reflected DIS PDUs identically in either direction. Multiple *disbridge* programs could connect arbitrary numbers of LANs with only a single *disbridge* needed for each new network addition. Although such an approach is inconvenient and a somewhat inefficient use of bandwidth, it can extend the broadcast/unicast DIS approach to large numbers of networks.

disbridge has been tested successfully with earlier versions of the underwater

virtual world, and also with the NPS Platform Foundation (Bailey 94). Fortunately *disbridge* is no longer needed since the newer multicast DIS version 2.0.3 can take advantage of the MBone to attain Internet-wide connectivity (Zeswitz 93).

Nevertheless only about a thousand subnets are currently connected to the MBone, and conceivably *disbridge* might someday be useful to connect networks independently of the MBone. Recommended future work includes upgrading *disbridge* to be compatible with future versions of the DIS library in unicast, broadcast or multicast modes.

B. *os9sender.c* Unix to OS-9 Socket Communications Client

```

/*****
Program:      os9sender.c

Description:   socket test program to pass input strings in 2 directions,
               especially socket from OS-9 auvsim1 to Irix fletch.cs

Revised:      31 MAY 94

Compilation:   unix> cc os9sender.c -o os9sender
               os-9> make os9sender

Execution:     host1>  os9server
               host2>  os9sender -r host1

Example:       fletch> os9server
               auvsim1> os9sender -r fletch

Execution options:

    -r -h -t   (first letters are sufficient, capital letters are OK too)

    -remote hostname  hostname.remote.net.address for client to connect to server
                      no default is present

    -help         display calling syntax

    -trace        turn on TRACE mode

References:     (1) (Gespac-provided) EVIRA EVLAN-11 Ethernet Data Link
                  Controller for the G64/G96 Bus/EVTCP Internet Package
                  technical manuals
                (2) Internetworking with TCP/IP Volume I: Principles,
                  Protocols and Architectures, Douglas E. Comer,
                  Prentice Hall, Englewood Cliffs NJ, 1991
                (3) Internetworking with TCP/IP Volume II: Design,
                  Implementation and Internals, Douglas E. Comer and
                  David L. Stevens, Prentice Hall, Englewood Cliffs NJ, 1991
                (4) IRIX Network Programming Guide, Silicon Graphics Inc.
                (5) An Advanced 4.3BSD Interprocess Communication Tutorial,
                  Samuel J. Leffler, Robert S. Fabry, William N. Joy,
                  Phil Lapsley, Steve Miller and Chris Torek, undated
                (6) Real-Time Programming Tutorial, Bill Mannel, SGI Expo,
                  Silicon Graphics Inc., 23 May 93
*****/
```

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Status: Tested satisfactory Irix<==>Irix, OS-9<==>OS-9, Irix<==>OS-9

Future work: Consider implementation as an inetd 'superserver' daemon.
 Ensure compatibility with DIS v2.0 protocols when available.

add #elif (sun) defines

Comments, suggestions and corrections are welcome!

```

*****/
/* Irix defines in /usr/include */
#if defined(sgi)

#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <signal.h>
#include <string.h>

/* OS-9 subdirectories /DEFS, /DEFS/INET */
#else
#include <stdio.h>
#include <types.h>
#include <inet/socket.h>
#include <inet/in.h>
#include <inet/netdb.h>
#include <signal.h>
#include <errno.h>

#endif

#include <time.h>

/* One stream socket is used with adequate throughput */
/* (although two could work, no performance improvement is expected) */

/* Be careful that you reserve these port numbers to prevent collisions */
/* from other processes requesting ports on your system: */

#define DISBRIDGE_TCP_PORT 2056 /* disbridge program, server & client */
/* NPS Autonomous Underwater Vehicle (AUV) */
/* Underwater Virtual World (UVW) */

#define AUVSIM1_TCP_PORT_0 3210 /* os9sender <==> os9server test programs */
#define AUVSIM1_TCP_PORT_1 3211 /* auv execution level <==> virtual world */
#define AUVSIM1_TCP_PORT_2 3212 /* port for future use */
#define AUVSIM1_TCP_PORT_3 3213 /* port for future use */
#define AUVSIM1_TCP_PORT_4 3214 /* port for future use */
#define AUVSIM1_TCP_PORT_5 3215 /* port for future use */
#define AUVSIM1_TCP_PORT_6 3216 /* port for future use */
#define AUVSIM1_TCP_PORT_7 3217 /* port for future use */

```

```

#define AUVSIM1_TCP_PORT_8      3218 /*          port for future use          */
#define AUVSIM1_TCP_PORT_9      3219 /*          port for future use          */

# define TRUE  1
# define FALSE 0

#define SOCKET_QUEUE_SIZE  5      /* max allowed by TCP/IP              */

/* function prototypes *****/
/* Note that function prototype parameters may need to be deleted if the
   C compiler used is not an ANSI compiler (e.g. OS-9 K&R C compiler) */
void shutdown_os9sender ();

/* global variable definitions *****/
static int      TRACE = 0;          /* 1 = trace on, 0 = trace off */
static int      socket_descriptor,
               socket_accepted,
               socket_stream;

static int      socket_length = 255;
static int      bytes_received, bytes_read, bytes_written,
               bytes_left, bytes_sent;

int             shutdown_signal_received = FALSE;

static int      i
               print_help      = FALSE;

/*****/
/*****/
main (argc, argv)
{
    int argc; char **argv;    /* command line arguments */
    {
        char
            command_sent      [81],
            command_received [81],
            remote_host_name [60];

        FILE
            *netstat_fileptr;

        struct sockaddr_in
            server_address;

        register struct hostent *server_entity;

        char
            test_buffer [81];

        static char
            *ptr;
        static char
            *remote_buffer;

/*****/
/* Begin execution, parse command line */
for (i = 1; i < argc; i++)
{
    if ((argv[i][0] != '-') || print_help)
    {

```

```

        print_help = TRUE;
        break;
    }
    switch (argv[i][1]) /* switch based on current command line parameter */
    {
        case 'h': /* help */
        case 'H': /* Help */
        case '?': /* Help */
            print_help = TRUE;
            break;

        case 'r': /* remote hostname tells client who to connect to */
        case 'R':
            /* get remotehost name */
            if (i+1 < argc) strcpy (remote_host_name, argv[++i]);
            else print_help = TRUE;
            break;

        case 't': /* TRACE feature */
        case 'T':
            TRACE = 1;
            break;

        default: /* no command line entry parameter present */
            print_help = TRUE;
    }

    /* end switch based on current command line parameter */
    /* end for */

    if (argc == 1 || print_help) /* print help string *****/
    {
        printf ("Usage: os9sender -remote hostname [-help] [-trace]\n");
        exit (-1);
    }

    if (TRACE) printf("[os9sender TRACE on]\n");
    fflush (stdin);

    /* Command line parameter parse complete */

    /* *****/
    /* Initialize communications blocks */
    /* *****/

    /* set socket_length */

    socket_length = 81; /* maximum allowed packet size */

    /* *****/
    /* Initialize both client & server *****/

    /* Signal handlers for termination to override net_open () and net_close ()*/
    /* signal handlers. Otherwise you are unable to ^C kill this program. */

    #if defined(sgi)
        signal (SIGHUP, shutdown_os9sender); /* hangup */
        signal (SIGINT, shutdown_os9sender); /* interrupt character */
        signal (SIGKILL, shutdown_os9sender); /* kill signal from Unix */
        signal (SIGPIPE, shutdown_os9sender); /* broken pipe from other host */
        signal (SIGTERM, shutdown_os9sender); /* software termination */
    #endif

    /* *****/
    /* Initialize sender *****/

    /* start by finding default/desired remote host to connect to */
    {

```

```

server_entity = gethostbyname (remote_host_name);
if (server_entity == NULL)
{
    printf("os9sender -remote host (\\\"%s\\\") not found\\n",
        remote_host_name);
    exit (-1);
}
else if (TRACE)
    printf("os9sender remote host (\\\"%s\\\") located\\n", remote_host_name);

/* Client opens server port *****/

/* Fill in structure 'server_address' with the address of the      */
/* remote host (i.e. SERVER) that we want to connect with:        */

#if defined(sgi)
    bzero ((char *) &server_address, sizeof (server_address));
#endif
server_address.sin_family = AF_INET;      /* Internet protocol family */

/* copy server IP address into sockaddr_in struct server_address */
#if defined(sgi)
    bcopy (server_entity->h_addr, &(server_address.sin_addr.s_addr),
        server_entity->h_length);
#else
    strncpy(&(server_address.sin_addr.s_addr), server_entity->h_addr,
        server_entity->h_length);
#endif

/* make sure port is in network byte order */
server_address.sin_port = htons (AUVSIM1_TCP_PORT_0);

/* Open TCP (Internet stream) socket */
if ((socket_descriptor = socket (AF_INET, SOCK_STREAM, 0)) < 0 )
{
    printf ("os9sender client can't open server stream socket");
    exit (-1);
}
else if (TRACE)
    printf ("os9sender client opened server socket successfully\\n");

/* Connect to the server. Process will block/sleep until connection is
   is established. Timeout will return an error. */
if (connect (socket_descriptor,
    (struct sockaddr *) &server_address,
    sizeof (server_address)) < 0)
{
    printf ("os9sender client can't connect to server socket\\n");
    exit (-1);
}
else if (TRACE)
    printf("os9sender client connected to server socket successfully\\n");

) /* end initialization */

/*****
/* loop transferring telemetry until shutdown_signal_received: */
*****/

/* Two-way reflector: listen to local program and relay to remote host,
   listen to remote host and relay to local program */

socket_stream = socket_descriptor; /* client */

if (TRACE)
{
    printf ("os9sender CLIENT: socket_descriptor = %d,\\n", socket_descriptor);

```

```

        printf ("                socket_accepted   = %d,\n", socket_accepted);
        printf ("                socket_stream      = %d\n", socket_stream);
    }

/*****
/* test handshakes */

    write (socket_stream, "SUCCESS #2: os9sender connected to os9server!", 46);
    read  (socket_stream, test_buffer, 46);
    test_buffer [47] = '\n';
    printf ("test handshake between hosts: \n%s\n", test_buffer);

/*****

    /* initialize boolean for main loop control */

    shutdown_signal_received = FALSE;

while (shutdown_signal_received == FALSE) /* loop until shutdown.. TRUE */
{
    /*****/
    /* Sender block */
    /*****/

    /* read from local stdin, relay to remote host */

    gets (command_sent);

    bytes_received = strlen (command_sent);

    if (TRACE) printf ("[os9sender command_sent:%s]\n", command_sent);

    if (bytes_received < 0) /* read failure */
    {
        printf ("os9sender gets () from keyboard unsuccessful\n");
        shutdown_os9sender();
    }

    if (bytes_received > socket_length)
    {
        printf ("os9sender send_telemetry_to_server error: ");
        printf ("bytes_received too big for packet socket_length\n");
        printf ("");
        printf ("[bytes_received=%d] > [socket_length=%d]; ",
                bytes_received, socket_length);
        printf ("string truncated\n");
    }

    bytes_left      = socket_length;
    bytes_written    = 0;
    ptr             = command_sent;

    while ((bytes_left > 0) && (bytes_written >= 0)) /* write loop *****/
    {
        bytes_sent = write (socket_stream, ptr, bytes_left);

        if (bytes_sent < 0) bytes_written = bytes_sent;
        else if (bytes_sent > 0)
        {
            bytes_left  -= bytes_sent;
            bytes_written += bytes_sent;
            ptr          += bytes_sent;
        }

        if (TRACE)
            printf("os9sender send_telemetry_to_server loop bytes sent = %d\n",
                    bytes_sent);
    }
}

```

```

if (bytes_written < 0)
{
    printf ("os9sender send_telemetry_to_server () send failed, ");
    printf ("%d bytes_written\n", bytes_written);
}
else if (TRACE)
    printf ("os9sender send_telemetry_to_server total bytes sent = %d\n",
            bytes_written);

/*****
/* Check termination */
*****/

if (strcmp (command_sent, "shutdown", 8) == 0)
    shutdown_signal_received = TRUE;

if (shutdown_signal_received == TRUE)
{
    shutdown_os9sender ();
    break;
}

/*****
/* Receiver block */
*****/

/* listen to remote host, relay to local network/program */

bytes_left      = socket_length;
bytes_received   = 0;
ptr             = command_received;

while ((bytes_left > 0) && (bytes_received >= 0)) /* read loop *****/
{
    bytes_read = read (socket_stream, ptr, bytes_left);

    if (bytes_read < 0) bytes_received = bytes_read;
    else if (bytes_read > 0)
    {
        bytes_left      -= bytes_read;
        bytes_received += bytes_read;
        ptr             += bytes_read;
    }

    if (TRACE)
        printf ("os9sender receiver block loop bytes_read = %d\n",
                bytes_read);

    /* if nothing is waiting to be read, break out of read loop */
    if ((bytes_read == 0) && (bytes_received == 0)) break;
}

if (bytes_received < 0) /* failure */
{
    if (TRACE)
    {
        printf ("os9sender receiver block read failed, ");
        printf ("bytes_received = %d\n", bytes_received);
    }
}
else if (bytes_received == 0) /* no transfer */
{
    if (TRACE)
        printf ("os9sender get_PDU_from_other_host read received 0 bytes\n");
}
else if (bytes_received > 0) /* success */
    printf ("%s\n", command_received);

```

```

/*****
/* Check termination */
/*****

if (strcmp (command_received, "shutdown", 8) == 0)
    shutdown_signal_received = TRUE;

if (shutdown_signal_received)
{
    shutdown_os9sender ();
    break;
}

} /* end of while (shutdown==FALSE) indefinite loop */

shutdown_os9sender (); /* ensure shutdown_os9sender is always reached */

printf ("os9sender exit \n");

exit (0); /* os9sender complete */
}

/*****
/*****
/* end of main program */
/*****
/*****

/* Shutdown block */

void shutdown_os9sender ()
{
    if (TRACE) printf ("os9sender shutdown in progress ...\n");

    shutdown_signal_received = TRUE; /* in case entry was from signal handler */

    /* No need to send a message to other side that bridge is going down, */
    /* since SIGPIPE signal trigger may shutdown_os9sender() on other side? */

    if (close (socket_stream) == -1)
        printf ("os9sender close (socket_stream) failed\n");

    if (TRACE) printf ("os9sender shutdown_os9sender () complete\n");
    return;
} /* end shutdown_os9sender () */

/*****
/*****

```

C. *os9server.c* Unix to OS-9 Socket Communications Server

```

/*****
Program:      os9server.c

Description:   socket test program to pass input strings in 2 directions,
               especially socket from OS-9 auvsim1 to Irix auvsim4

Revised:      20 JAN 94

Compilation:   unix> cc os9server.c -o os9server
               os-9> make os9server

Execution:     host1>  os9server
               host2>  os9sender -r host1

Example:       fletch> os9server
               auvsim1> os9sender -r fletch

Execution options:

               -h -t  (first letters are sufficient, capital letters are OK too)
               -help  display calling syntax
               -trace  turn on TRACE mode

References:    (1) (Gespac-provided) EVIRA EVLAN-11 Ethernet Data Link
                  Controller for the G64/G96 Bus/EVTCIP Internet Package
                  technical manuals
               (2) Internetworking with TCP/IP Volume I: Principles,
                  Protocols and Architectures, Douglas E. Comer,
                  Prentice Hall, Englewood Cliffs NJ, 1991
               (3) Internetworking with TCP/IP Volume II: Design,
                  Implementation and Internals, Douglas E. Comer and
                  David L. Stevens, Prentice Hall, Englewood Cliffs NJ, 1991
               (4) IRIX Network Programming Guide, Silicon Graphics Inc.
               (5) An Advanced 4.3BSD Interprocess Communication Tutorial,
                  Samuel J. Leffler, Robert S. Fabry, William N. Joy,
                  Phil Lapsley, Steve Miller and Chris Torek, undated
               (6) Real-Time Programming Tutorial, Bill Mannel, SGI Expo,
                  Silicon Graphics Inc., 23 May 93

```

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Status: Tested satisfactory Irix<==>Irix, OS-9<==>OS-9, Irix<==>OS-9

Future work: Consider implementation as an inetd 'superserver' daemon.
Ensure compatibility with DIS v2.0 protocols when available.

Comments, suggestions and corrections are welcome!

```

*****
/* Irix defines in /usr/include */
#if defined(sgi)

#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#include <signal.h>
#include <string.h>

/* OS-9 subdirectories /DEFS, /DEFS/INET */
#else
#include <stdio.h>
#include <types.h>
#include <inet/socket.h>
#include <inet/in.h>
#include <inet/netdb.h>
#include <signal.h>
#include <errno.h>

#endif

#include <time.h>

/* One stream socket is used with adequate throughput */
/* (although two could work, no performance improvement is expected) */

/* Be careful that you reserve these port numbers to prevent collisions */
/* from other processes requesting ports on your system: */

#define DISBRIDGE_TCP_PORT 2056 /* disbridge program, server & client */

/* NPS Autonomous Underwater Vehicle (AUV) */
/* Underwater Virtual World (UVW) */

#define AUVSIM1_TCP_PORT_0 3210 /* os9sender <==> os9server test programs */
#define AUVSIM1_TCP_PORT_1 3211 /* auv execution level <==> virtual world */
#define AUVSIM1_TCP_PORT_2 3212 /* port for future use */
#define AUVSIM1_TCP_PORT_3 3213 /* port for future use */
#define AUVSIM1_TCP_PORT_4 3214 /* port for future use */
#define AUVSIM1_TCP_PORT_5 3215 /* port for future use */
#define AUVSIM1_TCP_PORT_6 3216 /* port for future use */
#define AUVSIM1_TCP_PORT_7 3217 /* port for future use */
#define AUVSIM1_TCP_PORT_8 3218 /* port for future use */
#define AUVSIM1_TCP_PORT_9 3219 /* port for future use */

```

```

# define TRUE 1
# define FALSE 0

#define SOCKET_QUEUE_SIZE 5          /* max allowed by TCP/IP */

/* function prototypes *****/
/* Note that function prototype parameters may need to be deleted if the
   C compiler used is not an ANSI compiler (e.g. OS-9 K&R C compiler) */
void shutdown_os9server ();

/* global variable definitions *****/
static int          TRACE = 0;          /* 1 = trace on, 0 = trace off */
static int          socket_descriptor,
                   socket_accepted,
                   socket_stream;

static int          socket_length = 256;

static int          bytes_received, bytes_read, bytes_written,
                   bytes_left, bytes_sent;

int                shutdown_signal_received;

static int          i = 0,
                   print_help = FALSE;

/*****
*****/
main (argc, argv)
{
    int argc; char **argv; /* command line arguments */
    char          command_sent [81],
                  command_received [81],
                  remote_host_name [60];

    FILE          *netstat_fileptr;

    struct sockaddr_in server_address;

    register struct hostent *server_entity;

    char          test_buffer [81];

    static char    *ptr;

/*****
*****/
/* Begin execution, parse command line */
for (i = 1; i < argc; i++)
{
    if ((argv[i][0] != '-') || print_help)
    {
        print_help = TRUE;
        break;
    }
    switch (argv[i][1]) /* switch based on current command line parameter */

```

```

        case 'h':      /* help */
        case 'H':      /* Help */
        case '?':      /* Help */
            print_help = TRUE;
            break;

        case 't':      /* TRACE feature */
        case 'T':
            TRACE = 1;
            break;

        default:       /* no command line entry parameter present */
            break;

    } /* end switch based on current command line parameter */
} /* end for */

if (print_help)      /* print help string *****/
{
    printf ("Usage:  os9server [-help] [-trace]\n");
    exit (-1);
}
if (TRACE) printf ("os9server TRACE on\n");
fflush (stdin);

/* Command line parameter parse complete */

/*****
 * Initialize communications blocks
 *****/

/* set socket_length */
socket_length = 81;      /* maximum allowed packet size */

/*****
 * Initialize both client & server
 *****/

/* Signal handlers for termination to override net_open () and net_close ()*/
/*   signal handlers.  Otherwise you are unable to ^C kill this program. */

#ifdef (sgi)
    signal (SIGHUP,  shutdown_os9server);      /* hangup */
    signal (SIGINT,  shutdown_os9server);      /* interrupt character */
    signal (SIGKILL, shutdown_os9server);      /* kill signal from Unix */
    signal (SIGPIPE, shutdown_os9server);      /* broken pipe from other host */
    signal (SIGTERM, shutdown_os9server);      /* software termination */
#endif

/*****
 * Initialize server
 *****/

/* setup to listen for client to attempt connection */
{
    /* Server opens server port *****/

    /* Open TCP (Internet stream) in socket */
    if ( (socket_descriptor = socket (AF_INET, SOCK_STREAM, 0)) < 0 )
    {
        printf ("os9server can't 'open' stream socket");
        exit (-1);
    }
    else if (TRACE)
        printf ("os9server socket 'open' successful\n");
}

```

```

/* Bind local address so client can talk to server */
#ifdef(sgi)
    bzero ((char *) &server_address, sizeof (server_address));
#endif
server_address.sin_family = AF_INET; /* Internet protocol family */

/* make sure port is in network byte order */
server_address.sin_addr.s_addr = htonl (INADDR_ANY);
server_address.sin_port = htons (AUVSIM1_TCP_PORT_0);

if (bind (
    socket_descriptor,
    (struct sockaddr *) &server_address,
    sizeof (server_address)) < 0)
{
    printf("os9server socket 'bind' unsuccessful\n");
    exit (-1);
}
else if (TRACE) printf ("os9server socket 'bind' successful\n");

/* prepare socket queue for connection requests using listen */
listen (socket_descriptor, SOCKET_QUEUE_SIZE);
if (TRACE)
    printf("os9server socket 'listen' successful ...\n");

/* Server 'accept' waits for client connections *****/
if (TRACE) printf ("os9server socket waiting to 'accept' ...\n");
bytes_received = sizeof (socket_descriptor);
while ((socket_accepted = accept ( socket_descriptor,
    &server_address,
    &bytes_received)) < 1) /* block */
{
    if (TRACE)
    {
        printf ("os9server socket 'accept' unsuccessful, ");
        printf ("sleeping 1 second ...\n");
        sleep (1);
    }
}
printf("os9server connection is open between networks.\n");

} /* end initialization */

/*****
/* loop transferring telemetry until shutdown_signal_received: */
*****/

/* Two-way reflector: listen to local program and relay to remote host,
listen to remote host and relay to local program */

socket_stream = socket_accepted; /* server */

if (TRACE)
{
    printf ("os9server SERVER: socket_descriptor = %d,\n", socket_descriptor);
    printf ("socket_accepted = %d,\n", socket_accepted);
    printf ("socket_stream = %d\n", socket_stream);
}

/*****
/* test handshakes */
*****/

write (socket_stream, "SUCCESS #1: os9server connected to os9sender!", 46);
read (socket_stream, test_buffer, 46);
test_buffer [47] = '\n';
printf ("test handshake between hosts: \n%s\n", test_buffer);

/*****
*****/

```

```

/* initialize boolean for main loop control */
shutdown_signal_received = FALSE;
while (shutdown_signal_received == FALSE)    /* loop until shutdown.. TRUE */
{
    /* Receiver block */
    /* listen to remote host, relay to local network/program */

    bytes_left      = socket_length;
    bytes_received   = 0;
    ptr             = command_received;

    while ((bytes_left > 0) && (bytes_received >= 0)) /* read loop */
    {
        bytes_read = read (socket_stream, ptr, bytes_left);

        if (bytes_read < 0) bytes_received = bytes_read;
        else if (bytes_read > 0)
        {
            bytes_left      -= bytes_read;
            bytes_received += bytes_read;
            ptr              += bytes_read;
        }
        if (TRACE)
            printf ("os9server receiver block loop bytes_read = %d\n",
                    bytes_read);

        /* if nothing is waiting to be read, break out of read loop */
        if ((bytes_read == 0) && (bytes_received == 0)) break;
    }

    if (bytes_received < 0) /* failure */
    {
        if (TRACE)
        {
            printf ("os9server receiver block read failed, ");
            printf ("bytes_received = %d\n", bytes_received);
        }
    }
    else if (bytes_received == 0) /* no transfer */
    {
        if (TRACE)
            printf ("os9server get_PDU_from_other_host read received 0 bytes\n");
    }
    else if (bytes_received > 0) /* success */
    {
        printf ("%s\n", command_received);

        /* Check termination */
        if (strcmp (command_received, "shutdown", 8) == 0)
            shutdown_signal_received = TRUE;

        if (shutdown_signal_received == TRUE)
        {
            shutdown_os9server ();
            break;
        }
    }
}

```

```

/* Sender block
/*****
/* read from local stdin, relay to remote host
*/

gets (command_sent);

bytes_received = strlen (command_sent);

if (TRACE) printf ("os9server command_sent:%s\n", command_sent);

if (bytes_received < 0) /* read failure
{
    printf ("os9server gets () from keyboard unsuccessful\n");
    shutdown_os9server ();
}

if (bytes_received > socket_length)
{
    printf ("os9server send_telemetry_to_server error: ");
    printf ("bytes_received too big for packet socket_length\n");
    printf ("");
    printf ("[bytes_received=%d] > [socket_length=%d]; ",
            bytes_received, socket_length);
    printf ("string truncated\n");
}

bytes_left      = socket_length;
bytes_written   = 0;
ptr            = command_sent;

while ((bytes_left > 0) && (bytes_written >= 0)) /* write loop *****/
{
    bytes_sent = write (socket_stream, ptr, bytes_left);

    if (bytes_sent < 0) bytes_written = bytes_sent;
    else if (bytes_sent > 0)
    {
        bytes_left      -= bytes_sent;
        bytes_written   += bytes_sent;
        ptr              += bytes_sent;
    }

    if (TRACE)
        printf("os9server send_telemetry_to_server loop bytes sent = %d\n",
                bytes_sent);
}

if (bytes_written < 0)
{
    printf ("os9server send_telemetry_to_server () send failed, ");
    printf ("%d bytes_written\n", bytes_written);
}
else if (TRACE)
    printf ("os9server send_telemetry_to_server total bytes sent = %d\n",
            bytes_written);

/*****
/* Check termination
/*****

if (strncmp (command_sent, "shutdown", 8) == 0)
    shutdown_signal_received = TRUE;

if (shutdown_signal_received == TRUE)
{
    shutdown_os9server ();
}

```

```

        break;
    }

} /* end of while (shutdown_signal_received==FALSE) indefinite loop */
shutdown_os9server ();          /* ensure shutdown_os9server is always reached */
printf ("os9server exit.\n");
exit (0); /* os9server complete */
}

/*****
*****
/* end of main program */
*****
*****/

/* Shutdown block */

void shutdown_os9server ()
{
    if (TRACE) printf ("os9server shutdown in progress ...\n");
    shutdown_signal_received = TRUE; /* in case entry was from signal handler */

    /* No need to send a message to other side that bridge is going down, */
    /* since SIGPIPE signal trigger may shutdown_os9sender() on other side? */

    if (close (socket_stream) == -1)
        printf ("os9server close (socket_stream) failed\n");

    if (TRACE) printf ("os9server shutdown_os9server () complete\n");

    return;
} /* end shutdown_os9server () */

/*****
*****/

```

D. *disbridge.c* LAN to LAN Connectivity for DIS without Multicast

```

/*****
Program:          disbridge.c

Description:       Relays DIS packets between LANs on different Internet hosts

Revised:          7 July 93   DIS version 1.3

Compilation:      % DIS-1.3/src>> make bridge

Execution:        % host1>> disbridge -server
                  % host2>> disbridge [-client] -remote host1.internet.address

Execution options:

-s -c -r -H -I -t (first letters are sufficient, capital letters are OK too)
                  -server server mode; must be running prior to client calling for it
                  [-client] client mode [default]; remote host must be specified and
                           have disbridge -server already running there

                  -remote hostname hostname.remote.net.address for client to connect to server

                  -help display calling syntax

                  -interface et0 will force use of a given device interface (e.g. "et0") for
                           multicast packet listening on the local net. disbridge will
                           attempt to open the first known device if the default device
                           fails. Only one parent process is allowed to use that
                           device on a given machine. Thus if you want to connect one
                           local area network (LAN) with another, each LAN must
                           dedicate one machine to disbridge. This appears to be an
                           unavoidable hardware/multicast restriction.

                  -trace turn on TRACE mode

References:       (1) Military Standard--Protocol Data Units for Entity
                   Information and Entity Interaction in a
                   Distributed Interactive Simulation (DIS),
                   Institute for Simulation and Training, University of
                   of Central Florida, Orlando FL, 30 OCT 91
                   (2) Internetworking with TCP/IP Volume I: Principles,
                   Protocols and Architectures, Douglas E. Comer,
                   Prentice Hall, Englewood Cliffs NJ, 1991
                   (3) Internetworking with TCP/IP Volume II: Design,
                   Implementation and Internals, Douglas E. Comer and
                   David L. Stevens, Prentice Hall, Englewood Cliffs NJ, 1991
                   (4) IRIX Network Programming Guide, Silicon Graphics Inc.
                   (5) An Advanced 4.3BSD Interprocess Communication Tutorial,
                   Samuel J. Leffler, Robert S. Fabry, William N. Joy,
                   Phil Lapsley, Steve Miller and Chris Torek, undated
                   (6) Real-Time Programming Tutorial, Bill Mannel, SGI Expo,
                   Silicon Graphics Inc., 23 May 93
                   (7) DIS v1.2 source library, John Locke, Naval Postgraduate
                   School, Monterey CA, 8 FEB 92
*****/
```

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Acknowledgement: Thanks to John Locke, Mike Macedonia & Dave Pratt for assistance.

Status: Tested satisfactorily for EntityStatePDUs using v1.2 DIS protocol.

Caveat: Currently transmits EntityStatePDUs after removing articulated parameters. This is due to articulated parameter pointers not surviving transmission of the PDU image over the socket.

running Testing to date has been exclusively on SGI wrkstations Irix 4.0.5E operating system

Future work: Consider implementation as an inetd 'superserver' daemon.
Ensure compatibility with DIS v2.0 protocols when available.
Consider conversion from iterative to concurrent processing if throughput performance needs improvement.
Initialize opposite hosts using ActivateRequest & ActivateReply exchanges, as well as DeActivateRequest & DeActivateReply exchanges.
Comments, suggestions and corrections are welcome!

```

*****/
#include "disdefs.h" /* DIS Library */

#include <netdb.h>
#include <netinet/in.h>
#include <sys/socket.h>
#include <stdio.h>
#include <time.h>
#include <sys/types.h>

/* One stream socket is used with adequate throughput */
/* (although two could work, no performance improvement is expected) */

/* Be careful that you reserve these port numbers to prevent collisions */
/* from other processes requesting ports on your system: */

#define DISBRIDGE_TCP_PORT 2056 /* disbridge program, server & client */

/* NPS Autonomous Underwater Vehicle (AUV) */
/* Underwater Virtual World (UVW) */

#define AUVSIM1_TCP_PORT_0 3210 /*
#define AUVSIM1_TCP_PORT_1 3211 /* for future use
#define AUVSIM1_TCP_PORT_2 3212 /*
#define AUVSIM1_TCP_PORT_3 3213 /*
#define AUVSIM1_TCP_PORT_4 3214 /*
#define AUVSIM1_TCP_PORT_5 3215 /*
#define AUVSIM1_TCP_PORT_6 3216 /*
#define AUVSIM1_TCP_PORT_7 3217 /*

```

```

#define AUVSIM1_TCP_PORT_8      3218 /*
#define AUVSIM1_TCP_PORT_9      3219 /*

#define SOCKET_QUEUE_SIZE      5      /* max allowed by TCP/IP
#define SOCKET_PADDING          10     /* a little extra buffer after each PDU

/* function prototypes *****/
/* Note that these function prototypes may need to be commented out if the
   C compiler used is not an ANSI compiler.
void shutdown_disbridge      (const int status);
void send_PDU_to_other_host  (char *send_PDU, PDUType send_type);
int  get_PDU_from_other_host (char **get_PDU, PDUType *get_type);
void print_PDU               (char      *pdu, PDUType      type);

/* global variable definitions *****/
static int      TRACE = 0;          /* 1 = trace on, 0 = trace off */
static int      socket_descriptor,
               socket_accepted,
               socket_stream;

/* maximum allowed socket length value = ETHERMTU [/sys/netinet/ifether.h]
/* see initialization code for actual value
static int      socket_length = ETHERMTU;

static int      bytes_received;

static char      *local_PDU;
static PDUType   local_PDU_type;

static char      *remote_PDU;
static PDUType   remote_PDU_type;

static int      CLIENT,            /* boolean variables */
               SERVER;

/* John Locke's carried-over variable definitions *****/
int      i          = 0,
         print_help  = FALSE,
         ethernet_flag = FALSE,
         nodes,
         read_flag,
         recvd       = 0,
         sent        = 0,
         write_flag;

extern unsigned short host_id;

char      *pdu,
         ethernet_interface [MAX_INTERF+1];

PDUType   type;

/*****/
/*****/

```

```

main (argc, argv)
    int argc; char **argv; /* command line arguments */
{
    char
        command [81],
        new_device_name [4],
        remote_host_name [60];

    int
        shutdown;

    FILE
        *netstat_fileptr;

    struct sockaddr_in
        server_address;

    register struct hostent *server_entity;

    char
        test_buffer [37];

    /******
    /* Begin execution, parse command line
    /* Default execution is server waiting for client request to read/write PDUs */

    SERVER = TRUE;
    CLIENT = FALSE;

    for (i = 1; i < argc; i++)
    {
        if ((argv[i][0] != '-') || print_help)
        {
            print_help = TRUE;
            break;
        }
        switch (argv[i][1]) /* switch based on current command line parameter */
        {
            case 'h': /* help */
            case 'H': /* Help */
            case '?': /* Help */
                print_help = TRUE;
                break;

            case 'i': /* Ethernet interface */
            case 'I': /* Ethernet Interface */
                ethernet_flag = TRUE;
                if (i+1 < argc) {
                    if (strlen(argv[i+1]) > MAX_INTERF) {
                        printf("%s: error: interface name exceeds %d chars\n",
                               argv[0], MAX_INTERF);
                        exit (-1);
                    } else {
                        strcpy (ethernet_interface, argv[++i]);
                    }
                } else
                    print_help = TRUE;
                break;

            case 'c': /* client initiates server for reading/writing PDUs */
            case 'C':
                CLIENT = TRUE;
                SERVER = FALSE;
                break;

            case 'r': /* remote hostname tells client who to connect to */
            case 'R':
                CLIENT = TRUE;
                SERVER = FALSE;
                /* get remotehost name */
                if (i+1 < argc) strcpy (remote_host_name, argv[++i]);
        }
    }
}

```

```

        else
            print_help = TRUE;
        break;

    case 's':          /* server waits for client request to read/write PDUs */
    case 'S':
        CLIENT = FALSE;
        SERVER = TRUE;
        break;

    case 't':          /* TRACE feature */
    case 'T':
        TRACE = 1;
        break;

    default:
        print_help = TRUE;
    } /* end switch */
} /* end for */

if (argc == 1 || print_help) /* print help string *****/
{
    printf ("Usage:  disbridge [-client -remote hostname | -server <default>]
\n");
    printf ("          [-i device#] [-help] [-trace]\n");
    exit (-1);
}
printf ("\n");

if (!ethernet_flag) strcpy (ethernet_interface, BCAST_INTERF); /* default */

if (net_open (ethernet_interface) == FALSE)
{
    printf ("disbridge net_open (\"%s\") failed,\n", ethernet_interface);
    printf ("    due to improper device number or device is already in use\n");
    net_close (); /* clean up after a deficient net_open () DIS function */
    /* this recovery procedure would be better located there */

    /* Show user what correct port number is */
    if (TRACE)
    {
        sprintf (command, "netstat -I");
        printf ("    netstat -I\n");
        system (command); /* display results of netstat -I command */
    }

    sprintf (command, "netstat -I > netstat.I");
    system (command);

    if ((netstat_fileptr = fopen ("netstat.I", "r")) == (FILE *) NULL)
    {
        fprintf ("disbridge failed to create local file netstat.I\n");
        shutdown_disbridge (1);
    }
    /* flush first line then read first device name from file netstat.I */
    while (command[0] != '\n') fscanf (netstat_fileptr, "%c", &command[0]);
    fscanf (netstat_fileptr, "%3s", new_device_name);
    fclose (netstat_fileptr);
    sprintf (command, "rm netstat.I");
    system (command);

    /* Fixed problem in the DIS library, bad net_close() call caused exit */
    strcpy (ethernet_interface, new_device_name);
    if (net_open (ethernet_interface) == FALSE)
    {
        printf ("disbridge net_open (\"%s\") failed,\n", ethernet_interface);
        printf ("    improper device number or device already in use\n");
        exit (-1);
    }
}

```

```

    )
    printf ("disbridge net_open (\\\"%s\\\") succeeded\\n", ethernet_interface);

/* Command line parameter parse complete */

/*****
/* Initialize communications blocks */
*****/

/* set socket_length */

/* socket_length = ETHERMTU;          */ /* maximum allowed packet size */
    socket_length = sizeof (EntityStatePDU) + SOCKET_PADDING;

/* Note that DIS protocol version 2 will convert 'unused' to PDU length field */
/*****
/* Initialize both client & server *****/

/* Signal handlers for termination to override net_open () and net_close ()*/
/*   signal handlers.  Otherwise you are unable to ^C kill this program. */

signal (SIGHUP, shutdown_disbridge); /* hangup */
signal (SIGINT, shutdown_disbridge); /* interrupt character */
signal (SIGKILL, shutdown_disbridge); /* kill signal from Unix */
signal (SIGPIPE, shutdown_disbridge); /* broken pipe from other host */
signal (SIGTERM, shutdown_disbridge); /* software termination */

/* Future work: implement inter-network initialization by sending
    SendActivateRequestPDU's for all entities on the local net
    to first inform the remote host of their existence */

/* not implemented - PDU's copied when received regardless of activation */
/*****
/* Initialize client *****/

if (CLIENT) /* start by finding remote host to connect to */
{
    server_entity = gethostbyname (remote_host_name);
    if (server_entity == NULL)
    {
        printf("disbridge -remote host (\\\"%s\\\") not found\\n",
            remote_host_name);
        exit (-1);
    }
    else if (TRACE)
        printf("disbridge remote host (\\\"%s\\\") located\\n", remote_host_name);

/* Client opens server port *****/

/* Fill in structure 'server_address' with the address of the
    remote host (i.e. SERVER) that we want to connect with */

bzero ((char *) &server_address, sizeof (server_address));
server_address.sin_family = AF_INET; /* Internet protocol family */

/* copy server IP address into sockaddr_in struct server_address */
bcopy (server_entity->h_addr, &(server_address.sin_addr.s_addr),
    server_entity->h_length);

/* make sure port is in network byte order */
server_address.sin_port = htons (DISBRIDGE_TCP_PORT);

```

```

/* Open TCP (Internet stream) socket */
if ( (socket_descriptor = socket (AF_INET, SOCK_STREAM, 0)) < 0 )
{
    printf ("disbridge client can't open server stream socket");
    exit (-1);
}
else if (TRACE)
    printf ("disbridge client open server socket successful\n");

/* Connect to the server. Process will block/sleep until connection is
   is established. Timeout will return an error. */
if (connect (
    socket_descriptor,
    (struct sockaddr *) &server_address,
    sizeof (server_address)) < 0)
{
    printf ("disbridge client can't connect to server socket\n");
    exit (-1);
}
else if (TRACE)
    printf ("disbridge client connect to server socket successful\n");

} /* end if (CLIENT) initialization */

/*****
/* Initialize server *****/
if (SERVER) /* setup to listen for client to attempt connection */
{
    /* Server opens server port *****/
    /* Open TCP (Internet stream) in socket */
    if ( (socket_descriptor = socket (AF_INET, SOCK_STREAM, 0)) < 0 )
    {
        printf ("disbridge server can't 'open' stream socket");
        exit (-1);
    }
    else if (TRACE)
        printf ("disbridge server socket 'open' successful\n");

    /* Bind local address so client can talk to server */
    bzero ((char *) &server_address, sizeof (server_address));
    server_address.sin_family = AF_INET; /* Internet protocol family */
    server_address.sin_addr.s_addr = htonl (INADDR_ANY);
    server_address.sin_port = htons (DISBRIDGE_TCP_PORT);

    if (bind (
        socket_descriptor,
        (struct sockaddr *) &server_address,
        sizeof (server_address)) < 0)
    {
        printf ("disbridge server socket 'bind' unsuccessful\n");
        exit (-1);
    }
    else if (TRACE) printf ("disbridge server socket 'bind' successful\n");

    /* prepare socket queue for connection requests using listen */
    listen (socket_descriptor, SOCKET_QUEUE_SIZE);
    if (TRACE)
        printf ("disbridge server socket 'listen' successful ...\n");

    /* Server 'accept' waits for client connections *****/
    if (TRACE) printf ("disbridge server socket waiting to 'accept' ...\n");
    bytes_received = sizeof (socket_descriptor);
    while ((socket_accepted = accept (socket_descriptor,
        &server_address,
        &bytes_received)) < 1) /* block */

```

```

        if (TRACE)
        {
            printf ("disbridge server socket 'accept' unsuccessful, ");
            printf ("sleeping 1 second ...\n");
            sleep (1);
        }
        printf("disbridge connection is open between networks.\n");

    } /* end if (SERVER) initialization */

/* ***** */
/* loop until shutdown: */
/* ***** */

/* Two-way reflector:  listen to local network and relay to remote host,
                       listen to remote host and relay to local network */

if      (SERVER)  socket_stream = socket_accepted;
else /* CLIENT */ socket_stream = socket_descriptor;

if (TRACE)
{
    if (CLIENT) printf ("disbridge CLIENT:  ");
    if (SERVER) printf ("disbridge SERVER:  ");
    printf("          socket_descriptor = %d,\n", socket_descriptor);
    printf("          socket_accepted   = %d,\n", socket_accepted);
    printf("          socket_stream      = %d\n", socket_stream);
}

/* ***** */
/* test handshakes */
/* ***** */

if (CLIENT)
    write (socket_stream, "disbridge CLIENT connected to SERVER", 36);
if (SERVER)
    write (socket_stream, "disbridge SERVER connected to CLIENT", 36);
read (socket_stream, test_buffer, 36);
test_buffer [37] = '\n';
printf ("test handshake between hosts:  %s\n", test_buffer);

/* ***** */

/* After this point the behaviors of the CLIENT and SERVER are identical
   so we no longer bother testing for which version is being executed */

shutdown = FALSE; /* initialize boolean for main loop control */
while (shutdown == FALSE) /* begin to loop indefinitely until shutdown met */
{
    /* ***** */
    /* Sender block */
    /* ***** */

    /* read local_PDU from local network, relay it to remote host */
    nodes = net_read (&local_PDU, &local_PDU_type); /* note pointers passed */

    if (nodes < 0) /* net_read failure */
    {
        printf ("disbridge net_read () of local PDU traffic unsuccessful\n");
        shutdown_disbridge (1);
    }
    else if (nodes > 0) /* at least one PDU found, print it if in TRACE mode */
    {
        if (TRACE)
        {
            printf ("disbridge net_read () local_PDU captured successfully:\n");

```

```

        print_PDU (local_PDU, local_PDU_type);
    }

    /* PDU found. No need to check origin tag prior to relaying it since
       DIS library will ensure that net_read () does not see PDUs that
       originated from the self process's net_write (). Such checks are
       essential at some level, or a pathological race condition will develop
       and possibly swamp both networks with duplicated PDU traffic. */

    send_PDU_to_other_host (local_PDU, local_PDU_type);
}
else /* nodes == 0, no pdu found, no action required except trace */
    if (TRACE)
        printf ("disbridge net_read () no local PDU traffic pending ...\n");

/* *****
/* Receiver block */
/* *****

/* listen to remote host, relay remote PDU to local network */
/* if remote_PDU found, net_write it */

if (get_PDU_from_other_host (&remote_PDU, &remote_PDU_type) > 0)
{
    if (TRACE)
    {
        printf ("disbridge get_PDU_from_other_host successful:\n");
        print_PDU (remote_PDU, remote_PDU_type);
        printf ("disbridge calling net_write () ");
        printf ("to issue remote_PDU locally ...\n");
    }
    if (net_write (remote_PDU, remote_PDU_type) == FALSE)
        printf ("disbridge net_write (remote_PDU) unsuccessful\n");

    else if (TRACE)
        printf ("disbridge net_write (remote_PDU) successful\n");
}
else if (TRACE) printf ("disbridge get_PDU_from_other_host unsuccessful\n");

/* *****
/* Check termination */
/* *****

if (shutdown) shutdown_disbridge (0);

if (TRACE)
{
    printf ("disbridge no PDUs pending, sleep (1) ...\n");
    sleep (1);
}
/* shutdown = TRUE; */

} /* end of while (shutdown==FALSE) indefinite loop */

shutdown_disbridge (0); /* ensure shutdown_disbridge is always reached */

exit (0); /* disbridge complete */
}
/* *****
/* *****
/* end of main program */
/* *****
/* *****

/* *****

```

```

/* Shutdown block
/*****
void shutdown_disbridge (status)

    const int status;

{
    if (TRACE) printf ("disbridge shutdown in progress ...\n");

    /* No need to send a message to other side that bridge is going down,
       since SIGPIPE signal triggers shutdown_disbridge () the other side */

    if (close (socket_stream) == -1)
        printf ("disbridge close (socket_stream) failed\n");

    net_close (); /* close local net port connection listening for DIS PDU's */
                 /* watch out for net_close side effects/interrupts disabled! */

    printf ("disbridge exit.\n");
    exit (status); /* status parameter indicates normal or abnormal exit */

} /* end shutdown_disbridge () */

/*****
void send_PDU_to_other_host (send_PDU, send_PDU_type)

    char      *send_PDU;
    PDUType    send_PDU_type;

{
    int          i, bytes_written, bytes_left, bytes_sent;
    char         *ptr;
    EntityStatePDU *cast_PDU;

    char PDU_character_buffer [ETHERMTU]; /* ETHERMTU: /sys/netinet/ifether.h */

    if (send_PDU_type == EntityStatePDU_Type)
    {
        /* prevent passing articulated parameter pointers */

        cast_PDU = (EntityStatePDU *) send_PDU;
        cast_PDU->num_articulat_params = 0;

        bcopy (send_PDU, PDU_character_buffer, socket_length);
        if (TRACE)
        {
            printf ("disbridge send_PDU_to_other_host socket_length = %d\n",
                    socket_length);
            printf ("disbridge send_PDU type: %d\n", send_PDU_type);
            printf ("disbridge send_PDU character_buffer = [");
            for (i=0; i < socket_length; i++)
                printf ("%x ", PDU_character_buffer [i]);
            printf ("]\n");
            printf ("disbridge send_PDU character_buffer = [");
            for (i=0; i < socket_length; i++)
                printf ("%c", PDU_character_buffer [i]);
            printf ("]\n"); fflush (stdout);
        }

        if (socket_length > ETHERMTU)
        {
            printf ("disbridge send_PDU_to_other_host error: ");
            printf ("PDU too big for packet");
            printf (" ");
            printf (" [PDU socket_length=%d] > [ETHERMTU=%d]; nothing sent\n",
                    socket_length, ETHERMTU);
            return;
        }
    }
}

```

```

    }

    bytes_left      = socket_length;
    bytes_written    = 0;
    ptr             = PDU_character_buffer;

    while ((bytes_left > 0) && (bytes_written >= 0))           /* write loop */
    {
        bytes_sent = write (socket_stream, ptr, bytes_left);

        if      (bytes_sent < 0) bytes_written = bytes_sent;
        else if (bytes_sent > 0)
        {
            bytes_left      -= bytes_sent;
            bytes_written    += bytes_sent;
            ptr              += bytes_sent;
        }
        if (TRACE)
            printf("disbridge send_PDU_to_other_host loop bytes sent = %d\n",
                   bytes_sent);
    }

    if (bytes_written <= 0)
    {
        printf ("disbridge send_PDU_to_other_host () send failed, ");
        printf ("%d bytes_written\n", bytes_written);
    }
    else if (TRACE)
        printf ("disbridge send_PDU_to_other_host total bytes_written = %d\n",
                bytes_written);
    else printf ("disbridge unsupported PDUType (%d), not passed to remote\n",
                send_PDU_type);
} /* end send_PDU_to_other_host () */

/*****
int get_PDU_from_other_host (get_PDU, get_PDU_type) /* returns 1 if PDU found */
{
    char    **get_PDU;
    PDUType *get_PDU_type;

    int      bytes_read, bytes_left;
    char      *ptr;

    static char      *remote_PDU_buffer;
    static PDUHeader *remote_header;

    remote_PDU_buffer = malloc (socket_length);
    if (remote_PDU_buffer == NULL)
    {
        printf
            ("disbridge get_PDU_from_other_host remote_PDU_buffer malloc error\n");
        return (0); /* no PDU returned */
    }
    bytes_left      = socket_length;
    bytes_received   = 0;
    ptr             = remote_PDU_buffer;

    while ((bytes_left > 0) && (bytes_received >= 0))           /* read loop */
    {
        bytes_read = read (socket_stream, ptr, bytes_left);

        if      (bytes_read < 0) bytes_received = bytes_read;
        else if (bytes_read > 0)
        {
            bytes_left      -= bytes_read;

```

```

        bytes_received += bytes_read;
        ptr            += bytes_read;
    }
    if (TRACE)
        printf ("disbridge get_PDU_from_other_host loop bytes_read = %d\n",
                bytes_read);

    /* if nothing is waiting to be read, break out of read loop */
    if ((bytes_read == 0) && (bytes_received == 0)) break;
}

if (bytes_received < 0) /* failure */
{
    if (TRACE)
    {
        printf ("disbridge get_PDU_from_other_host read failed, ");
        printf ("bytes_received = %d\n", bytes_received);
    }
    return (0); /* no PDU returned */
}
else if (bytes_received == 0) /* no transfer */
{
    if (TRACE)
        printf ("disbridge get_PDU_from_other_host read received 0 bytes\n");
    return (0); /* no PDU returned */
}
/* else (bytes_received > 0) /* success */

/* Cast and convert buffer to return remote_PDU and remote_PDY_type */

remote_header = (PDUHeader *) remote_PDU_buffer;
*get_PDU      = remote_PDU_buffer;
*get_PDU_type = (PDUType)      remote_header->type;

if (TRACE)
{
    printf("disbridge get_PDU_from_other_host read bytes_received = %3d \n",
           bytes_received);
    printf("disbridge get_PDU_from_other_host read socket_length = %3d \n",
           socket_length);
    printf ("disbridge remote_header get_PDU_type: %d\n", *get_PDU_type);
    printf ("disbridge get_PDU remote_PDU_buffer = [");
    for (i=0; i < socket_length; i++)
        printf ("%x ", remote_PDU_buffer[i]);
    printf ("]\n");
    printf ("disbridge get_PDU () remote_PDU_buffer = [");
    for (i=0; i < socket_length; i++)
        printf ("%c", remote_PDU_buffer[i]);
    printf ("]\n"); fflush (stdout);
    ptr = *get_PDU;
    printf ("disbridge get_PDU () get_PDU = [");
    for (i=0; i < socket_length; i++)
        printf ("%c", ptr[i]);
    printf ("]\n"); fflush (stdout);
}
return (1); /* PDU returned */
} /* end get_PDU_from_other_host () */

/*****

void print_PDU (pdu, type) /* from John Locke's test_it.c */
    char *pdu; PDUType type; /* modified to stand as a routine, */
                             /* no other changes made */
{
    /* example PDUs */
    EntityStatePDU *Espdu;

```

```

FirePDU                *Fpdu;
DetonationPDU          *Dpdu;
ServiceRequestPDU      *SRpdu;
ResupplyPDU            *Rpdu;
ResupplyCancelPDU      *RCpdu;
RepairCompletePDU      *RC_pdu;
RepairResponsePDU      *RRpdu;
CollisionPDU           *Cpdu;
ActivatRequestPDU      *ARpdu;
ActivatResponsePDU     *AR_pdu;
DeactivatRequestPDU    *DRpdu;
DeactivatResponsePDU   *DR_pdu;
EmitterPDU             *Epdu;
RadarPDU               *Rad_pdu;

ArticulatParamsNode    *APNptr;                /* list nodes */
SupplyQtyNode          *SQNptr;
RadarSystem            *rad_sys_ptr;
RadarSystemNode        *RSN_ptr;
RadarSystemsNode       *RSNptr;
StoresNode             *SNptr;
EmitterNode            *ENptr;
IlluminatedEntityNode  *IENptr;

/* Print PDU data received */
if (TRACE) printf("disbridge print_PDU () PDU Type = %d\n", type);
switch (type)
{
case (OtherPDU_Type):
    printf("Undefined PDU type (OtherPDU_Type) received.\n");
    break;
case (FirePDU_Type):
    printf("Got %d:FirePDU\n", FirePDU_Type);
    Fpdu = (FirePDU *) pdu;
    printf("site: %d\n", Fpdu->firing_entity_id.address.site);
    printf("range: %f\n", Fpdu->range);
    break;
case (EntityStatePDU_Type):
    printPDU((char *) pdu);
    break;
case (DetonationPDU_Type):
    printf("Got %d:DetonationPDU\n", DetonationPDU_Type);
    Dpdu = (DetonationPDU *) pdu;
    break;
case (ServiceRequestPDU_Type):
    printf("Got %d:ServiceRequestPDU\n", ServiceRequestPDU_Type);
    SRpdu = (ServiceRequestPDU *) pdu;
    printf("quantity = %f\n",
           SRpdu->supply_qty_head->supply_quantity.quantity);
    break;
case (ResupplyOfferPDU_Type):
    printf("Got %d:ResupplyOfferPDU\n", ResupplyOfferPDU_Type);
    Rpdu = (ResupplyPDU *) pdu;
    printf("offer quantity = %f\n",
           Rpdu->supply_qty_head->supply_quantity.quantity);
    break;
case (ResupplyReceivedPDU_Type):
    printf("Got %d:ResupplyReceivedPDU\n", ResupplyReceivedPDU_Type);
    Rpdu = (ResupplyPDU *) pdu;
    printf("received quantity = %f\n",
           Rpdu->supply_qty_head->supply_quantity.quantity);
    break;
case (ResupplyCancelPDU_Type):
    printf("Got %d:ResupplyCancelPDU\n", ResupplyCancelPDU_Type);
    break;
case (RepairCompletePDU_Type):
    printf("Got %d:RepairCompletePDU\n", RepairCompletePDU_Type);

```

```

        break;
    case (RepairResponsePDU_Type):
        printf("Got %d:RepairResponsePDU\n", RepairResponsePDU_Type);
        break;
    case (CollisionPDU_Type):
        printf("Got %d:CollisionPDU\n", CollisionPDU_Type);
        break;

    /* Experimental PDU Types */
    case (ActivatRequestPDU_Type):
        printf("Got %d:ActivatRequestPDU\n", ActivatRequestPDU_Type);
        ARpdu = (ActivatRequestPDU *) pdu;
        printf("radar_system = %d\n",
            ARpdu->radar_systems_head->radar_systems.radar_system);
        printf("stores qty = %f\n", ARpdu->stores_head->stores.quantity);
        printf("ID = %d\n",
            ARpdu->articulat_params_head->articulat_params.ID);
        break;
    case (ActivatResponsePDU_Type):
        printf("Got %d:ActivatResponsePDU\n", ActivatResponsePDU_Type);
        break;
    case (DeactivatRequestPDU_Type):
        printf("Got %d:DeactivatRequestPDU\n", DeactivatRequestPDU_Type);
        break;
    case (DeactivatResponsePDU_Type):
        printf("Got %d:DeactivatResponsePDU\n", DeactivatResponsePDU_Type);
        break;
    case (EmitterPDU_Type):
        printf("Got %d:EmitterPDU\n", EmitterPDU_Type);
        Epdu = (EmitterPDU *) pdu;
        printf("entity_type = %d\n", Epdu->entity_type);
        printf("num_emitters = %d\n", Epdu->num_emitters);
        printf("emitter_params.param_1 = %d\n",
            Epdu->emitter_head->emitter.emitter_params.param_1);
        break;
    case (RadarPDU_Type):
        printf("Got %d:RadarPDU\n", RadarPDU_Type);
        Rad_pdu = (RadarPDU *) pdu;
        printf("location_to_entity.x = %f\n",
            Rad_pdu->radar_system_head->radar_system.location_to_entity.x);
        rad_sys_ptr = &(Rad_pdu->radar_system_head->radar_system);
        printf("target_id.address.site = %X\n",
            rad_sys_ptr->illuminated_entity_head->illuminated_entity.
                target_id.address.site);
        break;

    default:
        printf("Invalid PDU type received.\n");
        break;
}
} /* end print_PDU () */

/*****
*****/

```

VIII. WORLD-WIDE WEB (WWW) HYPERMEDIA AND MULTICAST BACKBONE (MBone)

A. Introduction

The World-Wide Web (WWW) project has been defined as a "wide-area hypermedia information retrieval initiative aiming to give universal access to a large universe of documents" (Hughes 94). Fundamentally the WWW combines a name space consisting of any information store available on the Internet with a broad set of retrieval clients and servers, all of which can be connected by easily-defined hypertext markup language (*.html*) multimedia links. This globally-accessible combination of media, client programs, servers and hyperlinks can be conveniently utilized by humans or autonomous entities. The Web has fundamentally shifted the nature of information storage, access and retrieval (Hughes 94) (Berners-Lee 94a, 94b).

Universal Resource Locators (URLs) are a key WWW innovation. A block of information might contain text, document, image, sound clip, video clip, executable program, archived dataset or arbitrary stream. If that block of information exists on the Internet, it can be uniquely identified by host machine IP address, publicly visible local directory, local file name, and type of client needed for retrieval (such as anonymous ftp, hypertext browser or gopher). Ordinarily the local file name also includes an extension which identifies the media type (such as *.ps* for PostScript file or *.rgb* for an image). Thus the URL completely specifies everything needed to retrieve any type of electronic information resource. Example URLs appear in the list of references, e.g. (Hughes 94).

The Multicast Backbone (MBone) permits several-to-many simultaneous high-bandwidth communications streams across the Internet. Detailed information on MBone applications and use appears in (Macedonia, Brutzman 94). A customized session directory (*sd*) configuration file *.sd.tcl* is provided. This configuration file adjusts the *sd* interface at run time to enable automatic DIS connection of the

underwater virtual world *viewer* and automatic spawning of a *Mosaic* browser connection to the NPS AUV WWW Home Page. Thus, once a system has been configured using free software for *Mosaic*, MBone and this project, connection to an already-running underwater virtual world requires only a single button click from any compatible workstation on the Internet. Global connectivity and ease of use are thus demonstrated in order to further encourage remote collaborative research and large-scale widely-distributed virtual worlds.

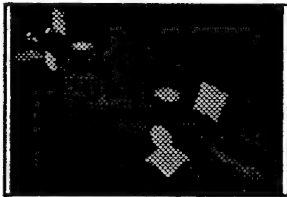
B. NPS AUV World-Wide Web Home Page

Hot links to other home pages, servers or media are portrayed by underlined text in the home page. Line breaks and page layout are handled automatically by the browser according to window and font size.

NPS Autonomous Underwater Vehicle (AUV) World-Wide Web Home Page

<ftp://taurus.cs.nps.navy.mil/pub/auv/auv.html>

NPS Autonomous Underwater Vehicle (AUV)

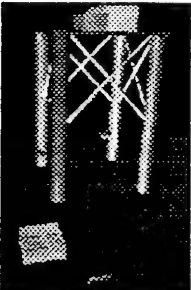


(about [Say...](#))

NPS AUV [publication abstracts](#) and [anonymous ftp server](#)

NPS AUV [graphics rendering](#) and a [wireframe rendering](#)

NPS AUV Underwater Virtual World



[finger auv@dude.cs.nps.navy.mil](finger:auv@dude.cs.nps.navy.mil) for a sample mission report.

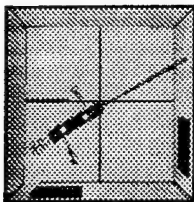
A free tar archive of the virtual world software is here: [auv-uvw.tar.Z](#), including source code and executable binaries that run on Silicon Graphics (SGI) workstations.

A [user installation guide](#) is available. Please let me know if you need help installing the virtual world. Research collaboration is welcome.

Here is another sample [NPS AUV mission report](#) run in the virtual world.

Additional supporting papers and programs used with the virtual world software are distributed separately:

- "From virtual world to reality: designing an autonomous underwater robot" paper and slides.
- Vehicle telemetry postscript plots (20 pages) for the SIGGRAPH mission.
- Mission script syntax for NPS AUV execution level control: mission.script.HELP file.
- www line mode World-Wide Web browser distribution page for the www anonymous ftp directory. **www** is used to make World-Wide Web queries from inside the virtual world. This program is needed if you want live text to speech capability. Put **www** in the /dynamics directory or have your system administrator install it.
- gnuplot plotting program distribution directory (and FAQ page). **gnuplot** is used to plot robot telemetry results. This program is needed if you want a plotting capability. Put it in the /execution directory or have your system administrator install it.
- MBone Multicast Backbone connection information. An MBone connection is needed if you want to participate in worldwide audio/video/DIS multicasts with the underwater virtual world. If you are a local user on the gravy cs.nps.navy.mil subnet, you don't have to download the full distribution but instead can copy the MBone session directory (**sd**) configuration file .sd.tcl and .mailcap mosaic initialization file to your root directory, and then paste the following .cshrc aliases into your root directory **.cshrc** file. After you **source .cshrc** you are ready to run **sd** and **mosaic**.



The NPS AUV Underwater Virtual World also appeared at **The Edge** exhibition at **SIGGRAPH 94**, July 26-29 in Orlando Florida USA. There was a simultaneous MBone multicast on the worldwide Internet all that week. Information resources from that exhibit include:

- [project abstract](#),
- [collaborator list](#),
- [people pages](#),
- [1000-word description](#) and [proposal](#) for exhibition in
- **The Edge** exhibition at **SIGGRAPH 94**, and
- information regarding the [audio/video multicast on the Internet MBone](#).

The Universal Resource Locator (URL) for this home page is
[*ftp://taurus.cs.nps.navy.mil/pub/auv/auv.html*](ftp://taurus.cs.nps.navy.mil/pub/auv/auv.html)

C. **Hypertext Markup Language (HTML) Syntax Summary**

The following HTML syntax summary will help decipher most of the home page document which follows in the next section. The key feature of HTML is that it describes document structure: images, the relative emphasis of text entries and links to other documents or files via URLs (NCSA 94b).

The rendered format of an HTML document can vary depending on the browser used to access it. This permits both graphics terminals and character-based terminals to each access and display a document, preserving contextual links throughout. URL media format is indicated by the filename extension. The ability to display movies, play sounds, and utilize other media depends on the capabilities of the connecting machine, the presence of 'viewer' programs which can receive and output the media after a handoff from the browser, and proper links between MIME types and browsers as configured in the user's *.mailcap* file.

The following is a short synopsis of key HTML markups. Markup tags are generally case insensitive. Blanks and skipped lines between markup tags have no effect.

See URL <http://www.ncsa.uiuc.edu/General/Internet/WWW/HTMLPrimer.html> for detailed information on HTML syntax.

 bold text

<I> *italics text* </I>

<P> inserts a paragraph break.

<HR> places a horizontal rule before the next item:

 places an inline image on the page.

 button text<
 places button text on the screen which retrieves "universal resource locator" when selected. Inline images can be used in place of text.

 starts an unnumbered list

 starts a list item

 starts another list item

 ends an unnumbered list

Figure 5. Hypertext Markup Language (HTML) Syntax Summary.

D. *auv.html* NPS AUV Home Page (Hypertext Markup Language)

```
<HEADER>
<TITLE> NPS Autonomous Underwater Vehicle (AUV) World-Wide Web Home Page</TITLE>
</HEADER>

<H1>      <A NAME=AUV> NPS Autonomous Underwater Vehicle (AUV) </H1>

          <A HREF="ftp://taurus.cs.nps.navy.mil/pub/auv/auv.iv.gif"><IMG
SRC="ftp://taurus.cs.nps.navy.mil/pub/auv/auv.iv.gif" ALT="NPS AUV logo"></A>
          <A HREF="ftp://taurus.cs.nps.navy.mil/pub/auv/nps_auv.au"><IMG
SRC="ftp://taurus.cs.nps.navy.mil/pub/mosaic/sound.xbm" ALT="sound icon"></A>.
          <A
HREF="http://www.tios.cs.utwente.nl:8001/say/?Naval+Postgraduate+School,Autonomous+Und
erwater+Vehicle"><IMG SRC="ftp://taurus.cs.nps.navy.mil/pub/mosaic/sound.xbm"
ALT="sound icon"></A>
          (about <A HREF = "http://www.tios.cs.utwente.nl/say/?" Say...</A>)

<H2>      NPS AUV <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/AUVPAPERS">
publication abstracts</A> and

          <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv"> anonymous ftp
server<i>(ftp://taurus.cs.nps.navy.mil/pub/auv)</i></A> </H2>

          <B> NPS AUV </B> <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/auv.iv.rgb.Z">
graphics rendering</A> and a
          <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/auv.iv.wireframe.rgb.Z"> wireframe rendering</A>
<P>

<hr>

<H1>      <A NAME="AUV-UVW"> NPS AUV Underwater Virtual World</H1>

          <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.gif"><IMG SRC =
"ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.gif" ALT="AUV Underwater Virtual World
image"></A> <P>

          Finger the NPS AUV account <A HREF =
"http://www.cs.indiana.edu/finger/gateway?auv@dude.cs.nps.navy.mil"><i>(finger
auv@dude.cs.nps.navy.mil)</i></A> for a sample mission report.<P>

          <B>      <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.tar.Z">A free tar
archive of the virtual world software is here: auv-uvw.tar.Z</A> </B>
          including source code and executable binaries that run on Silicon Graphics
(SGI) workstations.<P>

          A <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.virtual-world.INSTALL">user installation
guide</A>
          is available. Please let me know if you need help installing the virtual
world. Research collaboration is welcome. <P>

          Here is another sample <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/auv-uvw.virtual-world.README">NPS AUV mission
report</A> run in the virtual world. <P>

          Additional supporting papers and programs used with the virtual world
software are distributed separately:
          <ul>
          <li>      <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/aaai92ws.ps.Z"><i>"From
virtual world to reality: designing an autonomous underwater robot"</i> paper</A> and
          <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/aaai92ws.slides.ps.Z">slides</A>.
```

```

    <li>    <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/AUV_telemetry.ps.Z"><B>Vehicle telemetry</B>
postscript plots (20 pages) for the SIGGRAPH mission</A>.

    <li>    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/mission.script.HELP">
Mission script syntax for NPS AUV execution level control</A>: mission.script.HELP
file.

    <li>    <A HREF =
"http://info.cern.ch/hypertext/WWW/LineMode/Defaults/Distribution.html"><B>www</B>
line mode World-Wide Web browser</A> distribution page for the
    <A HREF = "ftp://info.cern.ch/pub/www/src/"><B>www</B> anonymous ftp
directory</A>.
    <b>www</b> is used to make World-Wide Web queries from inside the virtual
world. This program is needed if you want live text to speech capability.
    Put <b>www</b> in the /dynamics directory or have your system administrator
install it.

    <li>    <A HREF = "http://www.cs.dartmouth.edu/gnuplot/">
<B>gnuplot</B> plotting program</A> distribution directory (and
    <A HREF = "ftp://ftp.dartmouth.edu/pub/gnuplot/faq/gpt_faq.html"> FAQ
page</A>.
    <b>gnuplot</b> is used to plot robot telemetry results. This program is
needed if you want a plotting capability.
    Put it in the /execution directory or have your system administrator
install it.

    <li>    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/mosaic/mbone.html"><B>MBone</B>
Multicast Backbone</A> connection information.
    An MBone connection is needed if you want to participate in worldwide
audio/video/DIS multicasts with the underwater virtual world. <P>
    If you are a local user on the gravity.cs.nps.navy.mil subnet, you don't
have to download the full distribution but instead can copy the MBone session director
(<b>sd</b>), configuration file
    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/.sd.tcl">
<B>.sd.tcl</B></A> and
    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/.mailcap"><B>.mailcap</B>
mosaic initialization file</A> to your root directory, and then paste the following
    <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/.cshrc-excerpt"><B>.cshrc</B> aliases</A> into
your root directory <B>.cshrc</B> file. After you <B>source .cshrc</b> you are ready
to run <b>sd</b> and <b>mosaic</b>. <P>

</ul>

    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/pool-search.gif"> <IMG SRC
= "ftp://taurus.cs.nps.navy.mil/pub/auv/pool-search.gif" ALT="AUV pool search
image"></A><P>

    The <B>NPS AUV Underwater Virtual World</B> also appeared at
    <A HREF = "http://www.vsl.ist.ucf.edu/projects/edge/edge.html">
<B>The Edge</B></A> exhibition at
    <A HREF = "gopher://siggraph.org/00/conferences/siggraph94/gip/gip.txt">
<B>SIGGRAPH 94</B></A>, July 26-29 in Orlando Florida USA.
    There was a simultaneous
    <A HREF =
"ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/SIGGRAPH94-mbone.html"> MBone
multicast on the worldwide Internet</A> all that week.
    Information resources from that exhibit include:
    <ul>
    <li>    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/abstract.txt">
project abstract</A>,
    <li>    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/contacts.txt">
collaborator list</A>,
    <li>    <A HREF = "ftp://taurus.cs.nps.navy.mil/pub/pratts/home.html">
people pages</A>,
    <li>    <A HREF =

```

"ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/edge_description.txt"> 1000-word description and
 <A HREF =
 "ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/edge_proposal.ps.Z"> proposal
 for exhibition in

 The Edge exhibition at

 SIGGRAPH 94, and
 information regarding the <A HREF =
 "ftp://taurus.cs.nps.navy.mil/pub/auv/SIGGRAPH94/SIGGRAPH94-mbone.html">audio/video
 multicast on the Internet Mbone.

<hr>

<H1> IEEE Oceanic Engineering Society AUV 94 Conference</H1>

 <IMG SRC =
 "ftp://taurus.cs.nps.navy.mil/pub/auv/auv94.logo.gif" ALT="AUV 94 logo"> <P>

AUV 94 took place July 19-20 1994 in Cambridge Massachusetts USA.

 Conference Program in text and

 postscript formats,

 Video Proceedings & broadcast information, and the

 Video Proceedings abstract booklet.

We were able to broadcast the video proceedings and selected sessions over
 the Mbone.

Conference e-mail queries may be sent to <i>auv94@ieee.org</i> <P>

<hr>

<H2> Other good stuff! </H2>

 Symposium on
 Autonomous Systems in Mine Countermeasures at NPS April 4-6 1995. <P>

Unmanned Untethered Submersible Technology (UUST) 93 <A HREF =
 "ftp://taurus.cs.nps.navy.mil/pub/auv/uust93_video_order.form"> video proceedings
 abstracts with order form <P>

 OS-9
 FAQ: the OS-9 real-time operating system is what we use in the vehicle.
 Also pertaining to OS-9 is
 Windsor Systems
 Home Page. <P>

 Tony
 Healey (healey@lex.me.nps.navy.mil),
 Bob
 McGhee (mcghee@cs.nps.navy.mil), and

 Don
 Brutzman (brutzman@nps.navy.mil)

 contact info <P>

return to
 NPS Home Page table of contents

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E. *.sd.tcl* Multicast Backbone (MBone) Configuration File

```
# $Header: sd_start.tcl,v 1.4 (Van Jacobson LBL)
#
# NOTE:      This file was modified from the default .sd.tcl
#            to support automatic execution of multicast DIS
#            virtual world programs for the NPS AUV and NPSNET,
#            and to automatically spawn mosaic when a URL is
#            present in the session advertisement.
#
#            Please report additions, comments and corrections to
#            Don Brutzman, brutzman@nps.navy.mil
#
#            last modified:  19 OCT 94
#
#            URL of this example file is:
#            ftp://taurus.cs.nps.navy.mil/pub/auv/.sd.tcl.auv-uvw
#
# tcl 'hocks' invoked when sd takes some action on a session.
#
# sd will invoke:
#   start_session  when the user asks to 'open' (start) a session
#   create_session just after the user creates a new session
#   heard_session  when announcement for a session is first heard
#   delete_session when the user or a timeout deletes a session
#
# When any of the above are invoked, the global array sd_sess
# contains all the information about the session to be started:
#   sd_sess(name)
#   sd_sess(description)
#   sd_sess(address)
#   sd_sess(ttl)
#   sd_sess(creator)
#   sd_sess(creator_id)
#   sd_sess(source_id)
#   sd_sess(arrival_time)
#   sd_sess(start_time)
#   sd_sess(end_time)
#   sd_sess(attributes)      (list of session attributes)
#   sd_sess(media)           (list of media names)
#
# For each media name there is an array containing the information
# about that media:
#   sd_smedia(port)
#   sd_smedia(conf_id)
#   sd_smedia(attributes)    (list of media attributes)
#
# Media and session attributes are strings of the form "name" or
# "name:value".
#
# Some global state information is available in array sd_priv:
#   sd_priv(audio)           (= 0 if audio disabled with -a)
#   sd_priv(video)           (= 0 if video disabled with -v)
#   sd_priv(whiteboard)      (= 0 if wb disabled with -w)
#
proc start_session {} {
    global sd_sess sd_priv mosaic

    # thanks to Bill Fenner of Navy Research Lab for posting this addition.
    # start up Mosaic if there is a URL in the description.
    if {[regexp {[a-zA-Z]+://[^ ]+} $sd_sess(description) url]} {
        exec $mosaic -home $url &
    }

    # invoke the appropriate start proc for each of the media
}
```

```

# if such a proc exists and that media is enabled.
foreach m $sd_sess(media) {
    if { [llength [info proc start_$m]] && $sd_priv($m) } {
        start_$m
    }
}

proc start_audio {} {
    global sd_sess sd_audio
    set audiofmt ""
    set packetfmt "-n"
    foreach a $sd_audio(attributes) {
        case $a {
            fmt:* { set audiofmt [string range $a 4 end] }
            vt { set packetfmt "-v" }
        }
    }
    set confaddr [format "%s/%s/%s/%s/%s" $sd_sess(address) \
        $sd_audio(port) $sd_audio(conf_id) $audiofmt $sd_sess(ttl)]
    global vat
    exec $vat -C $sd_sess(name) $packetfmt $confaddr &
}

proc start_video {} {
    global sd_sess sd_video
    set videofmt "nv"
    foreach a $sd_video(attributes) {
        case $a {
            fmt:* { set videofmt [string range $a 4 end] }
        }
    }
    case $videofmt {
        nv {
            global nv
            exec $nv -ttl $sd_sess(ttl) $sd_sess(address) \
                $sd_video(port) &
        }
        ivs {
            global ivs
            exec $ivs -a -r -T $sd_sess(ttl) \
                dest $sd_sess(address) &
        }
        jpg {
            global imm
            exec $imm -p $sd_video(port) -I $sd_sess(address) \
                -ttl $sd_sess(ttl) -n $sd_sess(name) &
        }
    }
}

proc start_whiteboard {} {
    global sd_sess sd_whiteboard wb
    set orient "-l"
    foreach a $sd_whiteboard(attributes) {
        case $a {
            orient:portrait { set orient -p }
            orient:landscape { set orient -l }
            orient:seascape { set orient +l }
            orient:dis-npsnet {
                global nps
                exec $nps -F "config.trg" -p $sd_video(port) \
                    -I $sd_sess(address) -t $sd_sess(ttl)
            }
        }
    }
    &
    # do not also execute whiteboard

```

```

        return
    }
    orient:dis-auv-uvw {
        global dis_auv_uvw
        global dis_auv_uvw_dir
        cd $dis_auv_uvw_dir
        exec $dis_auv_uvw -port

$sd_whiteboard(port) \
                                -address $sd_sess(address) &
                                cd ..
                                # do not also execute whiteboard
                                return
    }
}

global xpsview
# running xpsview is a bug fix to prevent irix 5.2 crash
puts stdout ""
puts stdout "Spawning dummy xpsview to avoid whiteboard bug crash under
Irix 5.2 ..."
exec $xpsview &
exec $wb -t $sd_sess(ttl) -C wb:$sd_sess(name) $orient \
    $sd_sess(address)/$sd_whiteboard(port) &
}

proc create_session {} {
}

proc heard_session {} {
}

proc delete_session {} {
}

#####
# set up media option menus for new session windows.

set sd_menu(whiteboard) "orient: portrait landscape seascape\
    dis-npsnet dis-auv-uvw"

set sd_menu(audio) "fmt: pcm pcm2 pcm4 idvi dvi2 dvi4 gsm lpc4 nvt"
set sd_menu(video) "fmt: nv ivs imm"

#####

# set up the command names

# Edit these to match your system locations & filenames, if necessary.
# The version of mosaic that you point to must not have a precompiled
# local home page hard-wired in the binary, or it won't redirect.

set vat "/n/elsie/work3/macedoni/video/vat"
set nv "/n/elsie/work3/macedoni/video/nv"
set ivs "/n/elsie/work3/macedoni/video/ivs"
set wb "/n/elsie/work3/macedoni/video/wb_src/wb"
set imm "/n/elsie/work3/macedoni/video/imm"

set mosaic "/n/dude/work/brutzman/xmosaic/Mosaic-sgi"
set xpsview xpsview

set npsnet "/n/bossie/work3/npsnetIV/npsnetIV"

set dis_auv_uvw_dir "/n/dude/work/brutzman/auv-uvw"
set dis_auv_uvw viewer

```

F. *.mailcap* Configuration File for *Mosaic* Multimedia Viewers

```
#####
# global mailcap file for mosaic on NPS gravy net  Don Brutzman  18 OCT 94 #
#####
# global unix system location:          /usr/local/lib/mosaic/mailcap #
# users can put their own preferences in  ~yourname/.mailcap          #
#                                                                            #
# edit directory paths as necessary for your machine                  #
#                                                                            #
# reference:  http://www.ncsa.uiuc.edu/SDG/Software/Mosaic/Docs/mailcap.html #
#                                                                            #
#       URL of this example file is:                                     #
#       ftp://taurus.cs.nps.navy.mil/pub/auv/.mailcap.auv-uvw         #
#                                                                            #
#####

application/postscript; xpsview %s

#####

# If you wish to use xplaygizmo ( ftp://ftp.ncsa.uiuc.edu/Mosaic/misc/ )
# video/mpeg; xplaygizmo -p mpeg_play %s
# Alternate mpeg_player which includes looping capability:
video/mpeg; /n/dude/work/brutzman/xmosaic/mpeg_player %s
# I don't think xplaygizmo is needed for small audio, but it is workable.
# It is helpful on longer files such as Internet Talk Radio.

audio/*; /n/dude/work/brutzman/xmosaic/xplaygizmo -p -q sfplay %s
# audio/*; sfplay %s

#####
#
# STILL NEEDED: dvi viewer (such as the one which works for mosaic on grus)
#
application/x-dvi; xdvi %s

#
# Note:  besides Mosaic, mailcap files are used by MIME-capable
#        multimedia mail handlers
#####

# Final note:  be sure to select /Options _Reload_Config Files from the menu
#              for any changes to be effective in your current session.
```

G. .cshrc Excerpts: Login Configurations for MBone and Mosaic

```
#####

# mbone aliases/paths [from ~brutzman/.cshrc]

# sd to start the session directory tool, everything else
# is invoked from the sd menu

set path = ($path ~macedoni/video ~macedoni/bin)
set path = ($path ~macedoni/video/wb_src ~macedoni/video/mm_src)

alias sd '~macedoni/video/sd &' # session directory
alias vat '~macedoni/video/vat' # visual audio tool
alias nv '~macedoni/video/nv' # net video
alias wb '~macedoni/video/wb_src/wb' # white board
alias xv '~macedoni/video/xv' # xview
alias imm '~macedoni/video/imm' # image monitor tool
alias imm2xv '~macedoni/video/mm2xv' # image monitor => xview
alias ivs '~macedoni/video/ivs' # INRIA videoconferencing system
# normally imm goes full screen, imm can use imm2xv for a window

# also copy the file ~brutzman/.sd.tcl to your home account
# so that the tools are initially set up properly!

# subscribe to local NPS list npsmbone@nps.navy.mil if you are interested

#####

# mosaic/world-wide-web browser aliases/paths - for gravynet users

set path = ($path ~brutzman/xmosaic)

alias mosaic '~brutzman/xmosaic/Mosaic-sgi
ftp://taurus.cs.nps.navy.mil/pub/mosaic/nps_mosaic.html#TOC &'

alias www '~brutzman/xmosaic/www
ftp://taurus.cs.nps.navy.mil/pub/mosaic/nps_mosaic.html '

alias lynx '~brutzman/xmosaic/lynx
ftp://taurus.cs.nps.navy.mil/pub/mosaic/nps_mosaic.html '

# also copy the .mailcap file to initialize mosaic

# cp ~brutzman/.mailcap .mailcap

#####

# URL of this example file is:
# ftp://taurus.cs.nps.navy.mil/pub/auv/.cshrc-excerpt.auv-uvw
```

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